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# Transportation Air Quality Analysis Sketch Planning Methods. Volume I Analysis Methods

Cambridge Systematics, Inc, MA

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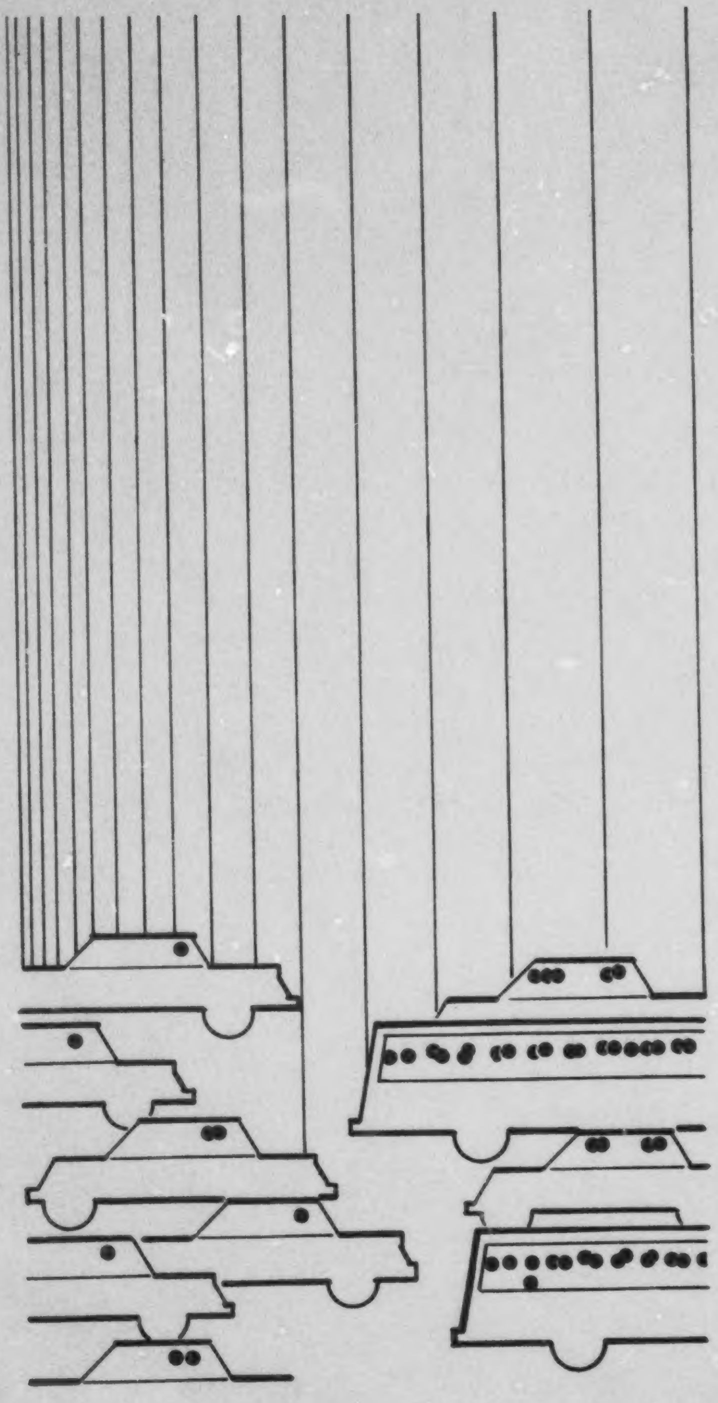

## sketch planning methods

## Volume I

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This information document is isssued by the Office of Transportation and Land Use Policy, U.S. Environmental Protection Agency, in response to Section 108(f) of the Clean Air Act. This document provides a range of quantitative analytical techniques to evaluate transportation measures and packages of alternative measures, and is designed to assist State and local air pollution control agencies and Section 174 lead planning agencies to perform transportation-air quality planning. Although examples are provided, this document is not intended as a substitute for the necessary case-by-case analysis by approporiate local planning organizations.

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16. Abstract

Analytical methodologies are described (in Volume 1) and illustrated (in Volume II) for use by metropolitan planning organizations and other state and local transportation agencies in analyzing the air quality potential of candidate urban transportation measures. As sketch planning techniques, the methods are designed to produce first-cut estimates of a proposed transportation measure's impact for a relatively small investment of time and effort. Quantitative methods oriented to auto restricted zones, high occupancy vehicle priorities, transit improvements, parking programs, carpool/vanpool incentives, and staggered work hours are provided. The methods use worksheet, programmable calculator, and computerized approaches to apply disaggregate behavioral models. They can be used to predict traveller demand as a function of transportation system characteristics, transportation facility operations as a function of their usage and their physical characteristics, and special impacts including vehicular emissions, fuel consumption, and operating costs. Guidelines are provided both to those responsible for designing the transportation-air quality analysis approaches in specific local areas, and to those who will carry out these analyses. In addition, references are provided to documents which provide additional detail on the methods.

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# TRANSPORTATION AIR QUALITY ANALYSIS SKETCH PLANNING METHODS

## VOLUME I

DECEMBER 1979

Prepared for:

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# PREFACE

The sketch planning methods described in this handbook have been assembled and illustrated under contract to the U.S. Environmental Protection Agency and the Urban Mass Transportation Administration in order to provide assistance to local transportation agencies as they conduct the planning and analyses required to develop the transportation portions of State Implementation Plans. The handbook is presented in two volumes:

Volume I: Analysis Methods

Volume II: Case Studies

The project was performed by Cambridge Systematics, Inc. Earl R. Ruiter, Project Manager, and John H. Suhrbier, Principal Responsible, provided the overall direction and management of the work performed. The development of the handbook benefited greatly from the advice provided by Marvin L. Manheim in the sketch planning applications of transportation analysis and programmable calculator methods areas, and by Adolph D. May (University of California, Berkeley), and Frederick A. Wagner (Wagner-McGee, Inc.) in the area of highway facility operations. The development or enhancement of specific analysis methods was carried out by Ellyn S. Eder and Melissa M. Laube. Additional major contributors to the handbook were Elizabeth A. Deakin, Lance A. Neumann, Daniel S. Nagin, Terry J Atherton, Scott D. Nason, William D. Byrne, and Greig Harvey.

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# CHAPTER 1. SKETCH PLANNING AND AIR QUALITY ANALYSIS

## 1.1 Purpose of this Handbook

This handbook presents a selection of techniques for transportation-air quality planning. It describes each technique and suggests the purposes and conditions for which it would be appropriate. The emphasis is on "sketch planning" techniques--ones which can produce a first-cut estimate of a proposed transportation measure's impact for a relatively small investment of time and effort.

The analysis approaches described here should be useful in developing the transportation portions of State Implementation Plans (SIP's), as required to meet national ambient air quality standards under the Clean Air Act, as amended (42 U.S.C. 1857 *et seq.*). The Act, and the joint Environmental Protection Agency/Department of Transportation guidelines issued pursuant to it, call for the analysis of a number of transportation measures which potentially could improve air quality (Table 1.1). The effects these measures would have--on travel; the transportation system; energy conservation; and a host of other social, environmental, economic, and financial concerns; as well as on air quality--must be evaluated within a broadly participatory, interactive planning process. Furthermore, the analyses must be completed expeditiously, in order to meet legislative deadlines for SIP adoptions and submittals. These combined requirements necessitate analytic capabilities which produce results quickly and yet provide accurate information on a wide range of impacts.

## TABLE 1.1

## Reasonably Available Transportation-Air Quality Measures to be Analyzed for SIP Revisions[1]

### Transportation System Measures:

- improved public transit (short- and long-range)
- exclusive bus and carpool lanes
- area-wide carpool programs
- private car restrictions
- on-street parking controls
- pedestrian malls
- park-and-ride and fringe parking lots
- employer programs to encourage carpooling and vanpooling, mass transit, bicycling and walking
- bicycle lanes and storage facilities
- staggered work hours (flexitime)
- road pricing to discourage single-occupancy auto trips
- traffic flow improvements

### Vehicle and Equipment Measures:

- inspection and maintenance programs
- alternative fuels or engines and other fleet vehicle controls
- other than light duty vehicle retrofit
- extreme cold start emission reduction programs
- controls on extended vehicle idling
- vapor recovery

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[1] Note: This report focuses on the first category of measures, those affecting the transportation system. The second catgory of measures are considered in some of the emissions estimation techniques, however.

Metropolitan Planning Organizations (MPO's) for the most part are taking the lead in transportation-air quality analysis. Often, however, the MPOs' analytical techniques center around large computer modelling systems which originally were designed to investigate the effects of long-term activity shifts and/or major capital investments in transportation. Such model systems tend to be too costly, too data-demanding, and too time consuming for use in analyzing the numerous alternatives to be considered in transportation-air quality planning. Because the models were not intended for analysis of transportation operations, management policies, or small changes in facilities, they often omit variables necessary to study such measures. Some of the variables which are included enter the models in ways that cannot respond to the influence of proposed actions, or that can do so only by recoding or reprogramming. Because the models were meant for regional studies, they frequently are so "aggregate" (i.e., coarse-scaled) that small or localized change cannot be discerned. The models usually do not have the capability to focus on a subarea or corridor except after considerable modification, and then only with a great deal of work. They rarely distinguish among various socioeconomic groups or other population subsamples. Thus, the conventional model systems are not well-suited for transportation-air quality planning--nor for most transportation system management (TSM) or transportation-energy conservation planning efforts, which likewise emphasize quick response analysis of management and operations policies and small capital investment projects. Methods which are cheaper, quicker, more flexible, and more responsive are needed.

In recent years, a number of sketch planning tools have been developed. They range from specialized techniques designed to address a particular type of measure or impact to general-purpose procedures and methodologies, and they cover a smililarly broad range of sophistication and complexity. In the following chapters, a selection of these sketch planning tools is reviewed, their applicability to various analysis problems is evaluated, and the resource requirements for each technique are assessed. Special emphasis is given to techniques suitable for transportation-air quality analysis, although most of the methods are more generally applicable to transportation system management planning and transportation-energy conservation planning. The techniques are grouped into three categories:

- travel demand analysis methods: methods which focus on user response to changes in transportation systems;
- facility operations analysis methods: method which focus on capacity, speeds, flows, and other operating characteristics; and
- special impacts analysis methods: methods for analyzing emissions and energy conservation;

However, a case could be made that several of the techniques cover two or even all three classifications. Within each category, the techniques are further grouped by their computational approach--manual, calculator program, and computer methods. Some relatively complex and costly methods are included where their potential usefulness or interest warrants attention; however, the bulk of the handbook is devoted to simpler and cheaper techniques.

In the remainder of this chapter, issues in transportation sketch planning analysis are reviewed, and considerations in designing an analysis approach are discussed. Chapters 2 through 4 then present the selected techniques. In Chapter 5, the discussion returns to technical issues in the design of an analysis approach. Case studies are provided in a separate Volume II.

This handbook is designed with two major types of readers in mind:

- Those who are designing transportation-air quality analysis approaches, and in doing so must select an appropriate set of analysis techniques.
- Those who are conducting transportation-air quality analyses, and require reference material on particular analysis methods.

Both types of readers can obtain the general introduction and required background to the terminology used in this handbook by reading the remainder of Chapter 1. Then, those requiring reference material can use the relevant parts of Chapters 2 through 4 to obtain an overview of various kinds of methods, descriptions of specific methods, and pointers to further reference material. Also, the Case Studies in Volume II can be used as extended examples of the use of these methods. Section 1.4 provides a guide to the methods discussed in Chapters 2 through 4.

Readers who must design specific local analysis approaches should skip directly from Chapter 1 to Chapter 5, which goes beyond the introductory material in the remainder of this Chapter, discussing a number of analysis design issues which must be considered. Then, further information on the methods found to be potentially useful can be obtained by going back to Chapters 2 through 4 and the Case Studies, again using Section 1.4 as a guide.

## 1.2 Basic Concepts in Sketch Planning

Sketch planning methods span a wide range of sophistication and complexity. The term covers a spectrum of approaches, from the drawing of qualitative and order-of-magnitude inferences based on experience in various settings (a case study approach) to use of computerized analysis packages. The unifying characteristic is that all are quick-response, expense-saving ways of evaluating the impacts of transportation proposals.

The economies associated with sketch planning can be achieved in any of several ways:

- by examining only those impacts which typically occur in the short run (e.g., five years or less)
- by reducing the geographic scale of the analysis, either by focusing on a particular subarea or corridor or by using large (i.e., aggregated) analysis zones
- by focusing on the effects on travel demand (i.e., user response to transportation system changes), treating facility operations as given (exogenous)
- by focusing on the effects on facility operations, treating travel demand as given (exogenous)
- by making other simplifications, such as using average values for variables, using coefficients or data developed in another area, or relying on inference and extrapolation.

Such simplifications are justifiable, but they must be treated with caution. The caution is based on the recognition that transportation interacts in complex ways with land use and socioeconomic factors. The characteristics of the transportation system--physical and operating--help to determine the amount of travel which takes place, which in turn affects the performance of the transportation system. Over the longer run, this interaction influences choices about household location, the location of firms, personal employment, auto ownership, and so on. Nonetheless, the first-order effects of a transportation measure can be viewed as limited both spatially and temporally.

Because transportation-air quality planning focuses primarily on the period between now and 1987, analysis can focus on near-term effects, checking only to make sure that detrimental longer-term effects are unlikely. Similarly, when a proposed measure applies to a limited geographic area, analysis can focus on that area, ignoring (for the most part) the "spin-off" effects which might occur in distant parts of the region. Thee simplifications should cause only minor losses of accuracy.

Interactions between demand for transportation and facility characteristics and operations are more complicated, as they occur continuously and iteratively. Thus, a complete, detailed analysis would represent the effects changes in demand would have on facilities' operations, and the effects changes in physical facilities or their operations would have on demand, using techniques termed "network equilibrium" or "capacity restraint". Nevertheless, a proposed measure can be classified as falling generally into one of two categories--it can affect demand primarily or it can affect facility characteristics and operations primarily. A number of analysis tools have been developed for each of these categories: some emphasize demand, some facilities. The analysis methods which emphasize demand represent facility characteristics as fixed or exogenous. Similarly, methods which emphasize facility characteristics generally represent demand in a simplified way.

The measures most frequently considered in transportation-air quality analysis are oriented toward:

- improving the flow of travel, reducing emissions per mile; or
- reducing the amount of travel by auto, by inducing travellers to walk, bicycle, use transit, or share-a-ride instead of driving by themselves.

The first type of measure tends to be facility/operations-oriented; the second type, demand-oriented. Either, however, may entail a physical change to the transportation system--adding a lane for high-occupancy vehicles, adding additional buses to a route, or may simply be a policy change--allowing right turns on red, eliminating tolls for carpools.

Impact analyses--of emissions; energy conservation; and other social, economic and environmental concerns--follow from the basic traveller behavior and facilities analyses. Once the changes in travel choices, average speed, and so on are known, many impact calculations are straightforward. However, from the perspective of decision-makers, the most pressing concern may be the incidence of impacts--which areas, or which groups within the population, are most affected by proposed measures. In order to examine the incidence of impacts, it is necessary to distinguish among such areas or population groups. This differentiation has been termed "market segmentation"; it can be based on a variety of factors, including income, auto ownership levels, availability of transit or other ridesharing modes, or trip destination (CBD/suburban). When data are sufficient to permit such market segmentation, the analysis can be more detailed and accurate and can reveal the distribution of travel responses and impacts among different groups or geographic areas.

## 1.3 The Range of Sketch Planning Techniques Available

Numerous sketch planning techniques have been developed in recent years. Three categories of such techniques are presented in this handbook:

- Travel demand analysis methods are those which predict traveller behavior in response to change in the transportation system. Techniques for trip generation, destination choice, mode share, and route choice are all reviewed.

- Facility operations analysis methods predict the operating characteristics of transportation facilities as a function of changes in capacity and operating policy. Intersection improvements, signal timing, capacity changes, and flow metering all are addressed by the techniques discussed.

- Special impact analysis methods focus on particular effects of transportation changes. Methods for assessing changes in vehicular emissions and fuel consumption are presented.

Within these categories, the techniques are further classified by the technology used in applying them:

- Manual methods are techniques which utilize worksheets, formulas, nomographs and the like to carry out hand calculations, as well as approaches for making use of data or study results from other urban areas.

- Programmable calculator methods are adaptations of manual methods which, by capitalizing on recent developments in inexpensive calculating equipment, allow for more detailed and precise analysis at no significant increase in effort.

- Computer-based methods are model systems for which time and expense are minimized by making simplifying assumptions or otherwise limiting the scope of the analysis.

Table 1.2 illustrates how the classification is used in this handbook. The methods were selected as representatives of the range of approaches which have been developed. The various techniques can accommodate different amounts and types of data, can be used at different levels of detail, and require various levels of staff expertise or experience,

## TABLE 1.2

## Typology of Sketch Planning Techniques

| Technology | Demand | Facility Operations | Special Impacts |
|---|---|---|---|
| Manual | worksheet mode choice<br>quick response urban travel estimation techniques<br>systematic data analysis | traffic flow formulae<br>graphical techniques<br>areawide traffic engineering method<br>transfer of experience | emissions worksheets<br>auto fuel consumption and operating costs |
| Programmable Calculator | HHGEN<br>2MODE-AGG<br>3MODE(VAN)-AGG | BUS | BUSPOL<br>ENERGY |
| Computer | CAPM<br>SRGP<br>transit sketch planning procedure | TRANSYT<br>FREQ | MOBILE1 |

labor, and other resources. Furthermore, techniques which are applicable to the full range of transportation-air quality measures have been included. The handbook thus should be useful in disparate settings and under disparate conditions.

An index to the methods listed in Table 1.2 is provided in Table 1.3. For each general class of method, and for each individual method, the appropriate section is indicated. This table also shows the Case Studies in Volume II in which the various methods are demonstrated, as well as the policies illustrated in each Case Study.

To illustrate the use of Table 1.3, consider first the analyst who wishes to see examples of the analysis of parking programs. Under this column, both Case Studies I and IV appear. Case Study I illustrates a number of manual demand and impact methods, and Case Study IV illustrates SRGP, a computer demand method. Secondly, consider an analyst who wishes to obtain information on calculator demand methods. The table provides Section references to the general overview of this class of methods (2.2), and to the three methods described in detail in this handbook (2.2.1, 2.2.2, 2.2.3). The table also shows that two Case Studies (II and III) illustrate the use of these methods.

TABLE 1.3

Cross-Reference Table for Analysis Methods and Case Studies

| | | VOLUME II: CASE STUDIES BY POLICY CLASS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| METHOD | VOL I SECTION | Auto Restricted Zones | HOV Priorities | Traffic Flow Improvements | Transit System Improvements | Parking Programs | Pricing Policies | Carpool/ Vanpool Incentives | Staggered Work Hours |
| Manual Demand | 2.1 | | | | | | | | |
| Pivot Point Mode Choice | 2.1.1 | | I | | I | I | | I | |
| Synthetic Mode Choice | 2.1.1 | | | | | | | | |
| Quick Response Urban Travel Estimation | 2.1.2 | | I | | I | I | | I | |
| Systematic Data Analysis | 2.1.3 | II | I | II | I,II | I | | I | |
| Calculator Demand | 2.2 | | | | | | | | |
| HHGEN - Household Samples | 2.2.1 | | III | | III | | | | |
| 2MODE-AGG - Synthetic Mode Choice | 2.2.2 | | III | | III | | | | |
| 3MODE(VAN)-AGG - Pivot Point Mode Choice | 2.2.3 | II | III | II | II,III | | | | |
| Computer Demand | 2.3 | | | | | | | | |
| CAPM - Community Aggregate Planning Model | 2.3.1 | | | | | | | | |
| SRGP - Short-Range Generalized Policy Analysis | 2.3.2 | | | | IV | IV | | IV | |
| Transit Sketch Planning | 2.3.3 | | | | V | | | | |
| Manual Facility Operations | 3.1 | | | | | | | | |
| Traffic Flow Formulae | 3.1.1 | | | | | | | | |
| Graphical Techniques | 3.1.2 | | | | | | | | |
| Areawide Traffic Engineering | 3.1.3 | | | VII | | | | | |
| Transfer of Experience | 3.1.4 | | | | | | | | |

TABLE 1.3 (Con't)

Cross-Reference Table for Analysis Methods and Case Studies

| | | VOLUME II: CASE STUDIES BY POLICY CLASS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| METHOD | VOL I SECTION | Auto Restricted Zones | HOV Priorities | Traffic Flow Improvements | Transit System Improvements | Parking Programs | Pricing Policies | Carpool/ Vanpool Incentives | Staggered Work Hours |
| Calculator Facility Operations | 3.2 | | | | | | | | |
| BUS - Bus Operations | 3.2.1 | | III | | III | | | | |
| Computer Facility Operations | 3.3 | | | | | | | | |
| TRANSYT - Arterial Street Systems Analyzer | 3.3.1 | | | | | | | | |
| FREQ - Freeway System Analyzer | 3.3.2 | | VI | VI | | | | | |
| Manual Impacts | 4.1 | | | | | | | | |
| Emissions Worksheets | 4.1 | II | I,III | II,VII | I,II,III | I | | I | |
| Auto Fuel Consumption and Operating Costs | 4.2 | II | | II | II | | | | |
| Calculator Impacts | 4.3 | | | | | | | | |
| BUSPOL/ENERGY - Bus Emissions and Fuel Consumption | 4.3 | | III | | III | | | | |
| Computer Impacts | 4.4 | | | | | | | | |
| MOBILE1 - Auto Emissions | 4.4 | | | | | | | | |

## 1.4 Choosing the Appropriate Technique

Factors which should be considered in selecting a sketch planning technique or method include:

- the types of effects the method can represent;
- the adequacy with which various kinds of impacts are addressed;
- the data processing capacity of the method;
- time and budget constraints;
- the skill level of available personnel;
- data availability and quality.

The first test of a method's suitability for a particular analysis application is whether the method can represent the effects of the measure(s) under study. For example, a method designed for analyzing how transit improvements affect transit mode share may be unable to represent the effects of carpool incentives on transit ridership. The user must hypotheize about the effects a measure might have, and then select an analysis technique, or a set of techniques, which can address those effects.

The adequacy with which various kind of impacts are addressed is another important consideration in selecting a technique. As discussed in the preceeding section, sketch planning analysis techniques generally focus on either the travel impacts or the facility operation impacts of a measure, treating the other impacts in a simplified fashion. The user will need to determine whether the primary effects of the measure(s) to be analyzed are on travel demand or on facility operations, and choose an analysis method accordingly. Note, however, that in many instances measures will have important effects on both demand and operations. The user should consider whether the method provides sufficient representation of all key impacts; in some cases, it may be necessary to partition the analysis into separate steps or to use several techniques to obtain reasonable results.

The suitability of a technique also is a function of its data processing capacity, in comparison to the amount of data which must be analyzed to provide the desired level of detail or number of results. From a practical point of view, for instance, a manual procedure might be a good choice for examining the areawide implications of improved transit service, but would be too cumbersome to use in analyzing the improvement on a route-by-route basis for a large transit system. Conversely, if only one or two routes are to be affected, it may be inappropriate to use a technique which can handle, or requires, large amounts of data; a simpler approach may suffice.

The appropriateness of a methodology to a particular analysis problem cannot be determined in isolation from such practical considerations as time, funding, and labor constraints and data availability. Time and budget limitations often will dictate that the user select a technique which provides less accurate and reliable results than may be desired in the ideal. The level of expenditure of time and money on an analysis also should be compatible with the scale and importance of the measure being considered. A first look at a proposed measure might best be done with a relatively fast, general technique, for instance.

The skill level of available personnel constitutes another important consideration, since there are substantial differences among various analysis methods with regard to their degree of difficulty. Technical skills are needed to apply the computer methodologies: if such skills are in short supply, one of the calculator or manual methods may be a better choice. On the other hand, many of the techniques requiring the fewest calculations do require the most judgment and experience in problem formulation and assessment; these requirements imply more senior-level involvement in the analysis process.

Limitations on the availability of required data often will prove to be a binding constraint on the amount of analysis which can be performed and its complexity. The sophistication of any methodology chosen should be commensurate with the quality of available data. Since the costs of data collection can amount to a substantial share of total analysis cost, data requirements should be taken into account in evaluating the cost-effectiveness of alternative methodologies.

In the following chapters, the selected techniques are reviewed. The presentation includes:

- a description of the technique's key features
- an assessment of its strengths and limitations
- suggestions on applicability

Among the factors considered are the following:

- measures addressed by the method
- nature of the analysis method--its theoretical or methodological features
- analysis time frame--short-, medium-, or long-range
- geographic scale--region, metropolitan area, corridor, localized
- behavioral representation--does the model attempt to replicate travel behavior or facility operation?

- critical assumptions--what assumptions are made which may have a significant effect on the results?
- ease of use and understanding--staff requirements to execute and/or interpret the method
- cost--personnel, computer or other costs required to execute the method (both initially and for repeated appliations)
- input requirements--data which must be supplied by user
- output--information provided by the method, especially outputs with specific relevance to air quality analyses
- previous use--is the method well tested and well documented; has it performed well in the past?

# CHAPTER 2 TECHNIQUES FOR ESTIMATING TRAVEL DEMAND IMPACTS

Travel demand analysis asks the question: How will travel behavior change in response to changes in the transportation system, land use and development patterns, and population attributes? Thus it examines where and how much travel will occur, at what times, by what mode, and over which routes.

Transportation-air quality planning focuses on incremental changes in the transportation system and their effects on travel. Such changes, cumulatively and over time, also may contribute to changes in land use and location and thus to the distribution of economic, social, and demographic characteristics. Nonetheless, over the time frame of primary interest in air quality, energy conservation, and transportation system management planning--a horizon of less than ten years--such secondary, "induced" changes are likely to be modest. (Note that other forces may change both land use and population attributes significantly, however.)

The recognition that analysis can focus on travel impacts, with less attention given to shifts in land use and population, gives rise to a number of sketch planning techniques for demand analysis. A selection of manual, calculator program, and computer program techniques is described in the following pages.

## 2.1 Manual Methods

Manual methods of forecasting travel demand can provide quick and inexpensive estimates of the impacts of transportation measures. Manual methods require less time, a lower level of staff specialization and less computing equipment than do many other techniques. On the other hand, the results they produce almost inevitably are less detailed and precise than those obtained with a more sophisticated methodology. The manual travel demand estimation procedures described here are representative of the broad range of methods which are available and are judged to be the most useful. The techniques which are included are:

- Worksheet mode choice methods:
    - Pivot-point mode choice method
    - Synthetic mode choice method

- Nomograph/formula techniques:
    - Quick response urban travel estimation package

- Systematic data analysis:
    - Transfer of data on travel characteristics and elasticities
    - Inference from previous study results or applications
    - Analysis of area-specific data

This variety of methods itself spans a considerable range of sophistication, detail and accuracy. A method could be used by itself, or in combination with others; for instance, an analysis of area-specific data could be used to evaluate the potential applicability of results from other studies, or to assess the reasonableness of transferring an elasticity. Furthermore, manual methods could be used to produce a preliminary estimate of a proposed measure's impacts, followed by the application of more complex calculator or computer program techniques if warranted.

Some caution must be exercised in the application of manual techniques--particularly the simpler ones. There is a distinct tradeoff between the simplicity of the method and the amount of judgment it takes to apply it appropriately. For example, transfer of data or results from one location to another necessitates a decision on the "similarity" of the two areas, which usually will require a fairly high level of experience and knowledge. In some ways, then, the more rigorous methods can be used more readily, simply because they are more generally applicable.

### 2.1.1 Worksheet Mode Choice Methods - Overview

Worksheet mode choice methods forecast choices of travel mode as functions of transportation level-of-service and transportation costs. The models can therefore be used to predict the impact of transportation policies which affect the level-of-service or cost of one or more transportation alternatives.

The first worksheet method described in this handbook is a "pivot-point" method--it predicts incremental changes in mode choice compared to a "base case" level. The "base case" may reflect existing conditions (e.g., current mode shares) or it may represent the conditions expected to be in existence as a result of other factors such as population growth, new development, and implementation of transportation measures other than the one being studied. (For example, the "base case" for 1982 might encompass a 10 percent increase in population over the 1979 level and a 20 percent increase in transit mode share as a result of system expansion in the 1979 to 1981 period. Changes in addition to these, such as additional bus service in 1982, would then cause an incremental change from the 1982 base case.)

The second worksheet method is a "synthetic" method--it synthesizes mode shares independent of any observed or base case conditions. It can be used to generate base case work trip mode shares as well as the impacts of specific policies.

Both of these worksheet methods are based on a specific mathematical formulation frequently used in mode choice models--the "multinomial logit" formulation. The basic multinomial logit form is used in the synthetic mode choice method. This form is:

$$P_m = \frac{e^{U_m}}{\sum\limits_{\text{all modes, } i} e^{U_i}}$$

where:

| | |
|---|---|
| $P_m$ | is the probability of choosing a given mode, m |
| $U_m$ | is the utility of mode m |
| e | is the base of natural logarithms, 2.718....... |

The incremental form of this model provided by the pivot-point method is:

$$P'_m = \frac{P_m e^{\Delta U_m}}{\sum\limits_{\text{all modes, } i} P_i \, e^{\Delta U_i}}$$

where:

| | |
|---|---|
| $P'_m$ | is the revised probability for mode m |
| $P_m$ | is the base probability for mode m |
| $\Delta U_m$ | is the change in utility for mode m |

In both of these forms, the mode-specific utilities, $U_m$, are typically defined as:

$$U_m = \sum_i a_{im} S_i + \sum_i b_{im} X_{im}$$

where:

| | |
|---|---|
| $S_i$ | is the $i^{th}$ socioeconomic variable; e.g., the traveller's income level or the employment density in the zone of attraction |
| $X_{im}$ | is the $i^{th}$ level-of-service variable for mode m; e.g., the in-vehicle travel time by transit |
| $a_{im}$ and $b_{im}$ | are estimated coefficients |

When the coefficients of the logit model (or any other travel demand model) are estimated using observations of individual tripmakers, then the models are termed "disaggregate" models. This is to distinguish these models from "aggregate" models--those estimated using the average characteristics of a number of tripmakers and their trips. Most conventional travel demand models are aggregate models. In recent years, however, the increased information available from individual observations has been used to obtain more detailed models using disaggregate estimation methods.

### a. Pivot-Point Mode Choice Method (14)

The pivot-point transportation demand estimation method produces estimates of incremental changes in modal shares for drive alone, shared ride, and transit modes of travel; changes in carpool size and auto occupancy; and changes in daily vehicle miles of travel in response to individual transportation measures or combinations of measures. Modal shares are predicted as a function of the relative "utility" of one or more modes. The changes in utility are determined on the basis of changes in the out-of-vehicle and in-vehicle travel time and cost resulting from each measure. The method is versatile with respect to the degree of market segmentation (number of population groups), number of zones, and geographic scale to which it can be applied. Once the analyst is familiar with the basic calculations required by the method and the base data is collected, the worksheets normally require only four hours to analyze each measure, assuming three or four market segments are defined.

Calculation Procedure--The methodology consists of the five basic and five supplemental worksheets included in Appendix A. Several steps are required prior to using the worksheets:

- First, the user must determine the appropriate geographic scale of analysis: regional, corridor, specific facility, etc.
- Second, the user must decide on the number and characteristics of "market segments" or population subgroups for which separate analyses will be performed. The analysis population can be differentiated into a number of discrete, relatively homogeneous subgroups, on the basis of such criteria as geographic location, transit availability, or trip orientation, to more accurately reflect differences in behavior among specific groups of travellers.

- Third, base case modal shares must be estimated for each market segment, taking into account the specific level-of-service or costs experienced by each of these subgroups. Methods of obtaining these base case modal shares are discussed in Section 5.4. Obviously, the method is much easier to use when these data are readily available.

After these initial three tasks have been performed, the user can begin to apply the worksheets. The worksheet sequence is represented graphically in Figure 2.1.

Base data on socioeconomic characteristics and travel patterns are entered on Worksheet I. Required data items consist of the following:

- Percent of total population analyzed
- Average annual household income
- Average number of non-work auto trips daily
- Base work trip modal shares (drive alone, shared ride and transit)
- Average carpool size
- Average trip length (for work and non-work trips)
- Average daily vehicle miles of travel (VMT)

For policies differentiating between 2-person and 3 or more-person carpools, additional data items required are:

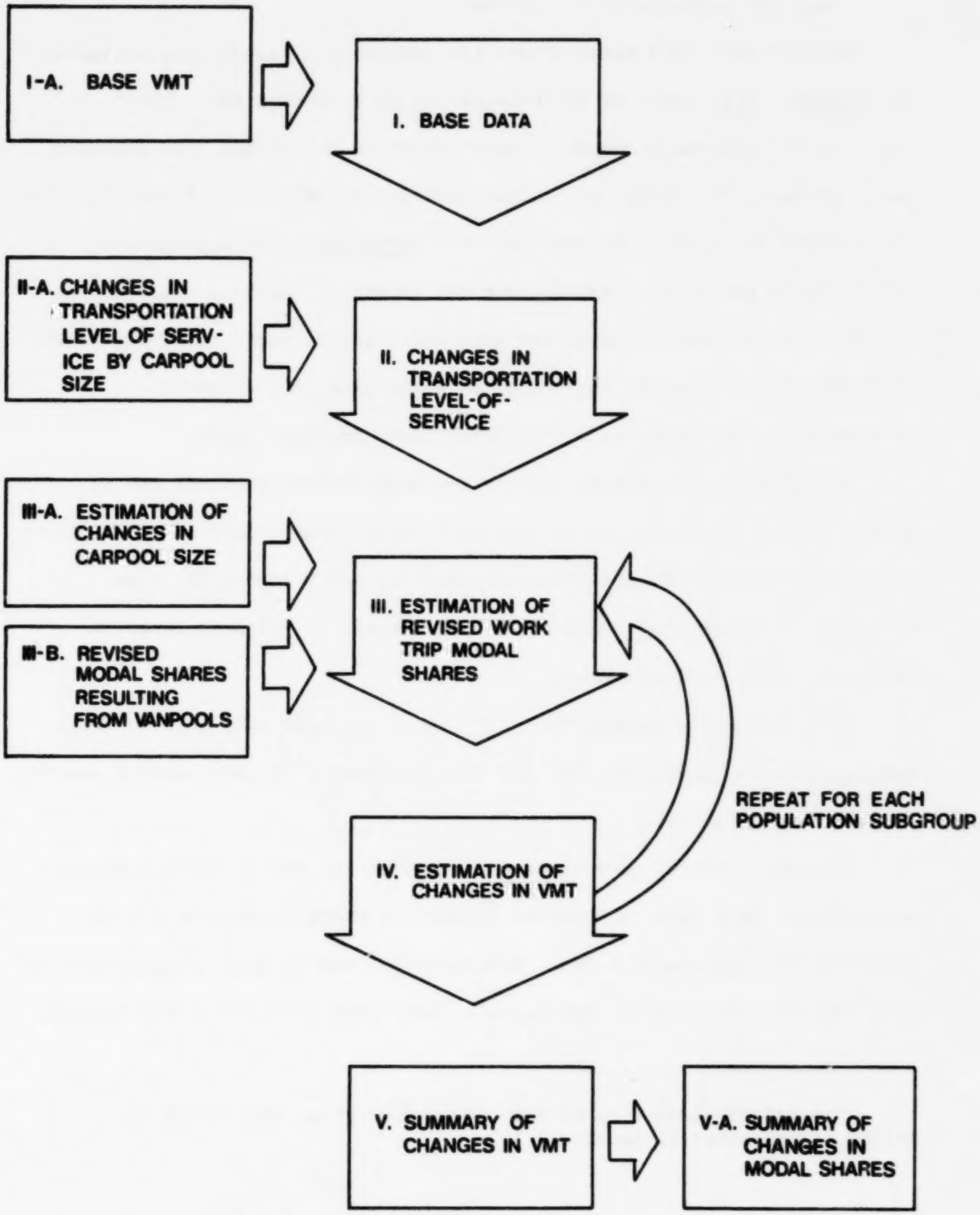
- Base modal shares for 2-person and 3 or more-person carpools
- Average size of 3 or more-person carpools

Worksheet II summarizes changes in transportation level-of-service and costs resulting from transportation measures under study. For transit, shared ride and drive alone alternatives, the following data are required:

- In-vehicle travel time
- Out-of-vehicle travel time (e.g. walk, wait, transfer, pickup, drop-off)

FIGURE 2.1

SEQUENCE OF BASIC AND SUPPLEMENTAL WORKSHEETS


I-A. BASE VMT
I. BASE DATA
II-A. CHANGES IN TRANSPORTATION LEVEL OF SERVICE BY CARPOOL SIZE
II. CHANGES IN TRANSPORTATION LEVEL-OF-SERVICE
III-A. ESTIMATION OF CHANGES IN CARPOOL SIZE
III-B. REVISED MODAL SHARES RESULTING FROM VANPOOLS
III. ESTIMATION OF REVISED WORK TRIP MODAL SHARES
REPEAT FOR EACH POPULATION SUBGROUP
IV. ESTIMATION OF CHANGES IN VMT
V. SUMMARY OF CHANGES IN VMT
V-A. SUMMARY OF CHANGES IN MODAL SHARES

- Out-of-pocket travel cost
- For the shared-ride mode only, whether or not its usage is subject to employer incentives

Revised work trip modal shares for each market segment are estimated on Worksheet III, based on the calculation of a "change in utility" function for each mode, which is used to obtain the change from existing modal shares. The change in utility function is calculated by multiplying the changes in travel time and cost from Worksheet II by appropriate coefficients and then exponentiating the product.[1] Default coefficients are included in the worksheet for this calculation; these coefficients are transferred from a model calibrated on Washington, D.C. data (5). User-supplied coefficients may be substituted in their place.

Worksheet IV translates the revised modal shares into changes in vehicle miles of travel, using base data, including numbers of workers per household, average vehicle occupancy, and average trip length, from Worksheet I. Worksheet V summarizes the changes in VMT calculated in Worksheet IV by market segment.

Note that while Worksheets I, II, and V are used only once for each policy analysis, Worksheets III and IV are repeated for each market segment included in the analysis.

Five supplemental worksheets are provided for use in certain special situations. Each form is numbered so that it corresponds with the basic worksheet it supplements. Thus, Worksheet I-A can be used to calculate the base VMT data required on Worksheet I. Worksheet II-A allows the user to differentiate changes in transportation levels of service by carpool size, specifically data for 3 or more-person versus 2-person carpools. Revised modal shares by carpool size are calculated on Worksheet III-A. Worksheet III-B can be used to estimate the changes in modal shares which would result from introduction of a vanpool program. The average areawide changes in the use of each transportation mode can be estimated using Worksheet V-A.

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[1] The mathematical form of the mode choice model underlying this method is described in Section 2.1.1.

Suggested Applications--The pivot-point travel demand method can be used to analyze the effects of virtually any measure which could induce changes in work trip mode choice as a result of changes it makes in the travel time or cost associated with a transportation alternative. It can be applied in the analysis of such measures as priority treatment of high-occupancy vehicles, traffic flow improvements, transit fare changes, pricing policies to discourage low occupancy vehicles, and carpool/vanpool incentives. Thus, the method is applicable for at least some aspects of the analysis of all major transportation-air quality measures, given sufficient information on transportation supply conditions, e.g. changes in travel time.

To apply the worksheets, it is necessary to represent the measure under study in terms of changes in travel time and/or cost. For some measures, e.g. transit fare policies, this is straightforward. However, for some measures (e.g. the designation of an exclusive bus lane), the user will be required to estimate the changes in travel time or cost through use of a highway facility operations model or some other procedure. Case Study I in Volume II demonstrates the use of the manual worksheets to analyze the effects of a high-occupancy vehicle lane; this example illustrates how the impacts of a program measure are translated into terms which can be used in the worksheets.

The method is not appropriate for some analyses, particularly those where travel time or cost changes are not major impacts. For instance:

- Auto restricted zones (ARZ's), in which the impact on trip distribution must be determined externally from the model
- Parking programs, in which supply constraints can be of major importance
- Variable work hours, in which the major focus of analysis concerns the number of employees who will be affected and their change in work hours.

### b. Synthetic Mode Choice Method (47)

The synthetic mode choice method, unlike the pivot-point methodology, can be used to estimate base case or existing work trip modal shares, as well as specific policy impacts. However, the synthetic model is more difficult to apply. In most cases, it is necessary to collect socio-economic and service level data by zone or by market segment, which is not required in the case of the pivot-point method.

The method entails manual application of the logit model described in Section 2.1.1. Modal shares are estimated as a function of the travel time and cost assocated with each mode. The worksheets in their present form can be used to forecast the split between two alternative modes. However, the technique can be adapted to include other modes.

Calculation Procedure--The method involves the use of the three worksheets included in Appendix B. Worksheet I, which contains the actual model, is used to estimate the passenger volumes for each of the two modes considered. A separate worksheet is required for each market segment studied. A utility function is calculated as the product of empirically estimated coefficients and in-vehicle and out-of-vehicle travel time and user cost variables, and exponentiating the resulting utility function. The worksheet includes default coefficients, which can be replaced by values supplied by the user. Similarly, the general form of the worksheets can be used with alternative logit models, especially if these have been developed for the metropolitan area being studied. The utility function yields the fractional shares for each mode, which are then multiplied by the total market segment volume to yield the actual volume of passengers in the market segment which use each mode.

Worksheet II is for analysis of variations in transit fare. The utilities of auto and transit alternatives are calculated as in Worksheet I, except that the transit fare term is separated from the other components of the calculations, which are subtotalled such that the value of the transit fare term can easily be varied and the total utility adjusted with a minimum of recalculation. A similar worksheet could be developed for analyzing the impact of travel time variations.

Worksheet III can be used to organize the information necessary to determine the level-of-service data required as input to Worksheets I and II. The various components of in-vehicle and out-of-vehicle time and cost for each alternative are entered on the worksheet and the necessary calculations performed.

Suggested Applications--The synthetic manual mode choice worksheets provide an efficient and accurate manual method for estimating base case modal shares, given adequate household and service level data by zone and/or other market segment. However, a procedure with reduced data requirements may be more appropriate for many applications.

If the synthetic manual mode choice method is used for estimation of base case modal shares, it is then relatively easy to apply the model to forecast the impacts of measures resulting in variations in fare or service levels. However, application of the method generally is more difficult than the use of the pivot-point methodology because the worksheets must be modified in many cases, and because its data requirements are greater. It may frequently be easier to use the pivot-point methodology to forecast policy impacts even if base case conditions are estimated with the synthetic model.

Because policies are represented in the synthetic model as revised travel costs and in-vehicle and out-of-vehicle travel times, in some instances it will be necessary to use facility operation methods, such as those discussed in Chapter 3, to translate the effects of a particular policy into measurable revisions in travel time which can be used as input to the synthetic demand model.

### 2.1.2 Nomograph/Formula Techniques--Overview

Nomograph/formula techniques merit consideration as sketch planning analysis tools for several reasons. The worksheet methods presented in this handbook directly estimate only work trip mode choice; when estimates of trip generation, distribution, or route assignment also are needed, nomographs or formulas can provide quick, if approximate, results. Also, although the nomograph/formula techniques are relatively imprecise for forecasting policy impacts, they are a simple way of estimating "base case" conditions, e.g. existing modal shares. A user may prefer them over the synthetic modal split worksheet when base case estimates can be approximate. Using nomograph/formula techniques to develop base case data along with pivot-point worksheet models to forecast the impacts of policy changes can be very effective from the standpoint of both forecasting accuracy and ease of application.

### a. Quick Response Urban Travel Estimation Techniques (18)

These techniques, developed as part of the National Cooperative Highway Research Program, provide manual methods for carrying out the four steps of the conventional urban transportation modelling process (trip generation, trip distribution, mode choice, and traffic assignment), as well as guidelines for determining auto occupancy and time of day distributions for different trip purposes. Each of the estimation procedures may be used alone; or they may be used in combination as an integrated travel forecasting system.

The procedures are applicable to areawide, corridor, or site analysis, with varying levels of computational detail provided for each of the steps. They utilize data and parameters drawn from typical urban settings, in tabular and nomograph form, and in the case of the mode choice procedure, travel demand models estimated on Washington, D.C., and Atlanta data.

The time required to use the techniques depends on the particular policy being analyzed, the impacts of interest, and the level of detail and accuracy desired in the analysis. An illustrative evaluation of residential development incorporating trip generation, distribution, assignment, mode split, and auto occupancy calculations required 60 hours of analyst time, not including data collection and preparation.

Like the computer-based travel demand modelling approaches on which they are based, the nomograph techniques are not capable of analyzing some transportation measures. Specifically, the mode choice procedure predicts only transit and auto shares and thus is unable to capture the effects of ridesharing incentive programs. Auto occupancy is predicted independent of travel level of service based on city size, trip purpose, time of day, income, and parking cost; income and parking cost are expressed only in relative terms (low, medium, high).

Although the data requirements for the models are flexible, in general, more data will be required to support an equivalent level of analysis with the nomograph technique than the pivot-point models. However, the nomograph method offers somewhat different analysis capabilities than the pivot-point model.

The following paragraphs briefly outline the features of the principal component of the nomograph techniques. Detailed descriptions of the techniques, sets of tables and nomographs, and sample calculations for each procedure and the model system as a whole are available (18).

Calculation Procedure--The estimation of trip generation involves the use of one of three tables, the choice depending on the scope of the analysis, availability of data, and level of detail and accuracy desired for the analysis:

- Table 2.1 provides trip generation rates for specific trip generators. Vehicle trip rates per day, peaking factors, typical auto occupancy, and typical transit share of person trips are reported for a large number of specific generator types ranging from single-family housing to hospitals.

- Table 2.2 contains estimated household person-trips classified by urban area population, household income, auto ownership, and trip purpose. This table is useful for estimating total travel in an urban area, but may also be used to develop estimates of total tripmaking to and from analysis zones given the distribution of population and income or auto ownership in each zone.

## TABLE 2.1

## Average Vehicle Trip Rates and Other Characteristics of Generators

| GENERATOR[b] | VEHICLE TRIPS[c] TO & FROM PER DAY PER |  | PERCENT TRIPS IN HOUR SHOWN |  |  | TYPICAL AUTO OCCUPANCY | TYPICAL % TRANSIT OF TOTAL PERSON TRIPS[d] |
|---|---|---|---|---|---|---|---|
|  | DWELLING UNIT | ACRE | A.M. PEAK | P.M. PEAK | PEAK HR. OF GEN. |  |  |
| **Residential Single Family** |  |  |  |  |  |  |  |
| 1 Du/acre | 9.3 | 9.3 | 8.0 | 10.8 | 10.8 | 1.62 | 3.2 |
| 2 Du/acre | 9.3 | 18.6 | 8.0 | 10.8 | 10.8 | 1.62 | 3.2 |
| 3 Du/acre | 10.2 | 30.6 | 8.0 | 10.8 | 10.8 | 1.67 | 3.2 |
| 4 Du/acre | 10.2 | 40.8 | 8.0 | 10.8 | 10.8 | 1.67 | 3.2 |
| 5 Du/acre | 9.1 | 45.5 | 8.0 | 10.8 | 10.8 | 1.62 | 3.2 |
| **Medium Density** (Duplex, Townhouses etc.) |  |  |  |  |  |  |  |
| 5 Du/acre | 7.0 | 35.0 | 8.0 | 10.8 | 10.8 | 1.57 | 5.6 |
| 10 Du/acre | 7.0 | 70.0 | 8.0 | 10.8 | 10.8 | 1.57 | 5.6 |
| 15 Du/acre | 7.0 | 105.0 | 8.0 | 10.8 | 10.8 | 1.57 | 5.6 |
| **Apartments** |  |  |  |  |  |  |  |
| 15 Du/acre | 6.0 | 90.0 | 7.9 | 10.8 | 10.8 | 1.56 | 12.4 |
| 25 Du/acre | 6.0 | 150.0 | 7.9 | 10.8 | 10.8 | 1.56 | 12.4 |
| 35 Du/acre | 6.0 | 210.0 | 7.9 | 10.8 | 10.8 | 1.56 | 12.4 |
| 50 Du/acre | 6.0 | 300.0 | 7.9 | 10.8 | 10.8 | 1.56 | 12.4 |
| 60 Du/acre | 6.0 | 360.0 | 7.9 | 10.8 | 10.8 | 1.56 | 12.4 |
| **Mobile Home Park** |  |  |  |  |  |  |  |
| 5 Du/acre | 5.5 | 27.5 | 8.3 | 10.8 | 12.5 | 1.54 | 1.0 |
| 10 Du/acre | 5.5 | 55.0 | 8.3 | 10.8 | 12.5 | 1.54 | 1.0 |
| 15 Du/acre | 5.5 | 82.5 | 8.3 | 10.8 | 12.5 | 1.54 | 1.0 |
| **Retirement Community** |  |  |  |  |  |  |  |
| 10 Du/acre | 3.5 | 35.0 | 12.1 | 12.1 | 12.1 | 1.48 | 6.0 |
| 15 Du/acre | 3.5 | 52.5 | 12.1 | 12.1 | 12.1 | 1.48 | 6.0 |
| 20 Du/acre | 3.5 | 70.0 | 12.1 | 12.1 | 12.1 | 1.48 | 6.0 |
| **Condominiums** |  |  |  |  |  |  |  |
| 10 Du/acre | 5.9 | 59.0 | 7.1 | 7.1 | 7.1 | 1.56 | 9.0 |
| 20 Du/acre | 5.9 | 118.0 | 7.1 | 7.1 | 7.1 | 1.56 | 9.0 |
| 30 Du/acre | 5.9 | 177.0 | 7.1 | 7.1 | 7.1 | 1.56 | 9.0 |
| **Planned Unit Develop.** |  |  |  |  |  |  |  |
| 5 Du/acre | 7.9 | 39.5 | 10.1 | 10.1 | 10.1 | 1.58 | 7.1 |
| 15 Du/acre | 7.9 | 118.5 | 10.1 | 10.1 | 10.1 | 1.58 | 7.1 |
| 25 Du/acre | 7.9 | 197.5 | 10.1 | 10.1 | 10.1 | 1.58 | 7.1 |
|  | SEE INDIVIDUAL GENERATOR BELOW |  |  |  |  |  |  |
| **Miscellaneous** |  |  |  |  |  |  |  |
| Service Station | Station<br>748 | Pump<br>133 | 1.5 | 3.0 | 4.0 | 1.55 | - |
| Race Track | Seat<br>0.61 | Attendee<br>1.08 | - | - | - | 2.05 | - |
| Pro-Baseball | 0.16 | 1.18 | - | - | - | 2.05 |  |
| Military Base | Military Personnel | Civilian Employees<br>Total Employees |  |  |  |  |  |
|  | 2.2 | 7.1<br>1.8 | - | - | - | 1.42 | - |
|  | 1000sq.ft. GFA | Employee<br>Acre |  |  |  |  |  |

Source: (18)

Table 2.1 (Continued)

| GENERATOR[b] | VEHICLE TRIPS[c] TO & FROM PER DAY PER | | | PERCENT TRIPS IN HOUR SHOWN | | | TYPICAL AUTO OCCUPANCY | TYPICAL % TRANSIT OF TOTAL PERSON TRIPS[d] |
|---|---|---|---|---|---|---|---|---|
| | (SEE INDIVIDUAL GENERATOR BELOW) | | | A.M. PEAK | P.M. PEAK | PEAK HR. OF GEN. | | |
| **Retail** | | | | | | | | |
| **Free Standing** | | | | | | | | |
| **Supermarket** | 135.3 | - | 1000 | 0 | 8.7 | 12.6 | 1.64 | 1 |
| **Discount Store** | 50.2 | 57.2 | - | 0 | 5.1 | 9.7 | 1.64 | 1 |
| **Discount Store with Super Mkt** | 81.2 | 30.3 | - | 0 | 6.9 | 11.1 | 1.64 | 1 |
| **Department Store** | 36.1 | 32.8 | 900 | - | - | - | 1.64 | 2 |
| **Auto Supply** | 88.8 | - | - | - | - | - | 1.64 | 1 |
| **New Car Dealer** | 44.3 | - | - | - | - | - | 1.64 | 1 |
| **Convenience** | | | | | | | | |
| (24 hrs.) | 577.0 | - | - | - | - | - | 1.64 | 1 |
| (15-16 hrs.) | 322.0 | - | - | - | - | - | 1.64 | 1 |
| **Shopping Center** | | | | | | | | |
| **Regional (over 1 million sq. ft.)** | 33.5 | 30.9 | 580 | 1.9 | 9.7 | 11.5 | 1.64 | 3 |
| (1/2-1 million sq.ft) | 34.7 | 20.4 | 370 | 2.8 | 9.6 | - | 1.64 | 3 |
| **Community (100,000-500,000 sq. ft.)** | 45.9 | 20.6 | 330 | - | 11.2 | 11.3 | 1.64 | 3 |
| **Neighborhood (under 100,000 sq. ft.)** | 97.0 | - | - | 3.3 | 11.5 | 12.4 | 1.64 | 3 |
| **Central Area (High Dens.)** | 40.0 | - | 900 | - | - | - | 1.64 | 12 |
| **Industrial/ Manufacturing** | | | | | | | | |
| **Free Standing** | | | | | | | | |
| **General Manufacturing** | 4.2 | 2.3 | 40.5 | 18.4 | 19.3 | 32.2 | 1.33 | 5 |
| **Warehouse** | 5.3 | 4.4 | 67.5 | 12.7 | 32.2 | - | 1.25 | 5 |
| **Research/ Develop.** | 5.1 | 2.4 | 60.8 | 21.1 | 20.4 | - | 1.33 | 5 |
| **Industrial Park** | 8.8 | 3.9 | 71.9 | 13.2 | 14.7 | - | 1.33 | 5 |
| **General Light Ind.** | 5.5 | 3.2 | 52.4 | 21.1 | 20.4 | 21.2 | 1.33 | 5 |
| **All Industry Avg.** | 5.5 | 3.0 | 59.9 | 15.8 | 19.4 | - | 1.40 | 5 |
| **Offices** | | | | | | | | |
| **General** | 11.7 | 3.5 | 145 | 20.7 | 19.1 | - | 1.35 | 5 |
| **Medical** | 63.5 | 25.0 | 426 | - | - | 8.5 | 1.45 | 5 |
| **Governmental** | 48.3 | 12.0 | 66 | 8.5 | 16.0 | - | 1.35 | 5 |
| **Engineering** | 23.0 | 3.5 | 282 | 16.9 | 14.6 | - | 1.35 | 5 |
| **Civic Center** | 25.0 | 6.1 | 33 | 9.0 | 11.4 | - | 1.35 | 5 |
| **Office Park** | 21.0 | 3.3 | 277 | 16.9 | 14.6 | - | 1.35 | 5 |
| **Research Center** | 9.3 | 3.1 | 37 | 16.0 | 18.5 | 20.2 | 1.35 | 5 |
| **Restaurants** | | | | | | | | |
| **Quality Restaurant** | 56.3 | - | 200 | 1.8 | 6.0 | 12.5 | 1.93 | 3 |
| **Other Sit-Down** | 198.5 | - | 932 | 29.0 | 6.4 | - | 1.93 | 3 |
| **Fast Food** | 533.0 | - | 1825 | 16.0 | 5.7 | - | 1.93 | 1 |
| **Banks** | 388 | 75 | - | - | - | - | 1.45 | - |
| **Parks & Recreation** | | | | | | | | |
| **Marina** | - | 259.0 | 18.5 | - | - | - | 2.05 | - |
| **Golf Course** | - | 34.2 | 7.4 | - | - | - | 2.05 | - |
| **Bowling** | - | - | 296.3 | - | - | - | 2.05 | - |
| **Participant sports** | - | - | 26.5 | - | - | - | 2.05 | - |
| **City Park** | - | - | 60.0 | - | - | - | 2.05 | - |
| **County Park** | - | 26.5 | 5.1 | - | - | - | 2.05 | - |
| **State Park** | - | 61.1 | 0.6 | - | - | - | 2.05 | - |
| **Wilderness Park** | - | - | 0.07 | - | - | - | 2.05 | - |

Table 2.1 (Continued)

| GENERATOR[b] | VEHICLE TRIPS[c] TO & FROM PER DAY PER | | | PERCENT TRIPS IN HOUR SHOWN | | | TYPICAL AUTO OCCUPANCY | TYPICAL % TRANSIT OF TOTAL PERSON TRIPS[d] |
|---|---|---|---|---|---|---|---|---|
| | 1000sq.ft. GFA | EMPLOYEE | ACRE | A.M. PEAK | P.M. PEAK | PEAK HR OF GEN. | | |
| **Parks & Recreation** (cont'd) | | | | | | | | |
| National Monument | - | - | 11.9 | - | - | - | 2.05 | - |
| Ocean Front | - | - | 21.6 | - | - | - | 2.05 | - |
| Lake/Boating | - | - | 3.6 | - | - | - | 2.05 | - |
| Animal Attractions | - | - | 72.2 | - | - | - | 2.05 | - |
| **Hospitals** | **Staff** | **Bed** | **Acre** | - | - | | | |
| All Categories | 6.1 | 14.8 | 40 | - | - | 11.7 | 1.40 | - |
| General | 5.9 | 14.0 | - | 18.0 | 9.0 | - | 1.42 | 17 |
| Childrens | 10.1 | 25.2 | - | - | - | | 1.42 | 17 |
| Convalescent | 4.5 | 3.2 | - | - | - | - | 1.42 | 10 |
| University | 7.8 | 37.0 | - | 12.5 | 10.5 | - | 1.41 | 10 |
| Veterans | 2.2 | 3.8 | | 11.0 | 16.5 | - | 1.32 | 10 |
| Nursing Home | - | 2.7 | - | 5.2 | 7.8 | 13.3 | 1.40 | 10 |
| Clinics | 5.9 | - | - | - | - | - | 1.40 | 10 |
| **Educational** | **Student** | **Staff** | | | | | | |
| All Categories | 1.8 | 13.6 | | - | - | - | 1.40 | - |
| Four Year Univ | 2.5 | 9.8 | | 11.0 | 9.0 | - | 1.40 | 13 |
| Jr.College | 1.5 | 28.2 | | 11.5 | 7.5 | 11.9 | 1.55 | 13 |
| Secondary School | 1.4 | 19.9 | | 11.5 | 4.9 | - | 1.55 | 4 |
| Elementary School | 0.6 | 11.7 | | 31.4 | 2.0 | - | 1.55 | 4 [e] |
| Combined Elem/Sec. | 0.8 | 11.8 | | - | - | - | 1.55 | 4 |
| Libraries | 41.8 | 51.0 | | - | - | 16.0 | 1.55 | 6 |
| **Airports** | **Take-Off/ Landing** | **Employee** | **Acre** | | | | | |
| General Aviation | 2.5 | 6.5 | 3.6 | 11.8 | 10.5 | 15.7 | 1.52 | 1 |
| Commercial | 11.8 | 16.8 | - | 9.7 | 17.3 | - | 1.52 | 3 |
| **Hotel/Motel** | **Room** | **Employee** | | | | | | |
| Hotel | 10.5 | 11.3 | | 7.9 | 5.7 | 8.3 | 1.56 | 2 |
| Motel | 9.6 | 10.6 | | 6.7 | 5.9 | 9.0 | 1.56 | 0 |
| Resort Hotel | 10.2 | 10.3 | | 2.6 | 6.8 | 7.8 | 1.93 | 0 |

a. The trip rates given are based on a limited number of studies and thus must be used with caution. The ITE Trip Generation Report(6) provides current data which is also periodically updated. The vehicle trip rates include external-internal and internal-external trip ends at generators as well as trucks, taxis and bus.

b. Most of the generators examined are located outside the central business districts of cities. The trip rates may thus be inapplicable to sites located within the dense urban core, particularly in large cities. Variations in generation rates may also exist because of the location of the generator either within a metropolitan area or outside that area.

c. The vehicle trip rates presented are actually volumes into and out of the site. As such, they may include some trips that would be passing the site on the adjacent street system, in any case, while making a trip for another reason, and they are induced to stop for impulse or convenience shopping, personal business or to drop off or pick up a passenger. The proportion of these trips has not been identified. Note also that ranges in trip rates can be expected and these can vary depending upon local conditions.

d. The typical transit % shown has a wide range of variation based on location within an urban area, level of service provided, etc., and as such, should be used only to provide gross approximations.

e. Does not include school bus transit.

TABLE 2.2

## Detailed Trip-Generation Characteristics

URBANIZED AREA POPULATION: 50,000-100,000

| Income Range 1970 $ (000's) | Avg Autos Per HH[d] | Average Daily Person Trips Per HH[e] | % HH by Autos Owned[b] | | | | Average Daily Person Trips Per HH by No. of Autos/HH[c] | | | | % Average Daily Person Trips by Purpose[f] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | 1 | 2 | 3+ | 0 | 1 | 2 | 3+ | HBW | HBNW | NHB |
| 0-3 | 0.56 | 4.5 | 53 | 39 | 7 | 1 | 2.0 | 6.5 | 11.5 | 12.5 | 21 | 57 | 22 |
| 3-4 | 0.81 | 6.8 | 32 | 58 | 10 | 1 | 2.2 | 8.0 | 13.0 | 15.0 | 21 | 57 | 22 |
| 4-5 | 0.88 | 8.4 | 26 | 61 | 12 | 1 | 2.6 | 9.5 | 14.5 | 16.5 | 21 | 57 | 22 |
| 5-6 | 0.99 | 10.2 | 20 | 62 | 17 | 1 | 3.0 | 11.0 | 15.5 | 18.0 | 18 | 59 | 23 |
| 6-7 | 1.07 | 11.9 | 15 | 64 | 20 | 1 | 3.0 | 12.5 | 16.5 | 19.5 | 18 | 59 | 23 |
| 7-8 | 1.17 | 13.2 | 11 | 64 | 23 | 2 | 3.5 | 13.3 | 17.0 | 21.5 | 16 | 61 | 23 |
| 8-9 | 1.25 | 14.4 | 8 | 62 | 28 | 2 | 4.8 | 14.0 | 17.5 | 22.5 | 16 | 61 | 23 |
| 9-10 | 1.31 | 15.1 | 6 | 60 | 32 | 2 | 5.5 | 14.3 | 17.5 | 24.0 | 16 | 61 | 23 |
| 10-12.5 | 1.47 | 16.4 | 3 | 49 | 44 | 3 | 6.2 | 15.0 | 18.5 | 25.5 | 15 | 62 | 23 |
| 12.5-15 | 1.69 | 17.7 | 2 | 38 | 52 | 8 | 6.1 | 15.0 | 19.0 | 25.5 | 14 | 62 | 24 |
| 15-20 | 1.85 | 18.0 | 2 | 28 | 57 | 13 | 6.0 | 13.5 | 19.5 | 23.0 | 13 | 62 | 25 |
| 20-25 | 2.03 | 19.0 | 1 | 21 | 58 | 20 | 6.0 | 13.0 | 20.0 | 23.0 | 13 | 62 | 25 |
| 25+ | 2.07 | 19.2 | 1 | 19 | 59 | 21 | 6.0 | 12.5 | 20.0 | 23.0 | 13 | 62 | 25 |
| Weighted Average | 1.55 | 14.1 | 12 | 47 | 35 | 6 | 4.6 | 12.6 | 17.2 | 21.4 | 16 | 61 | 23 |

URBANIZED AREA POPULATION: 100,000-250,000

| Income Range 1970 $ (000's) | Avg Autos Per HH[d] | Average Daily Person Trips Per HH[e] | % HH by Autos Owned[b] | | | | Average Daily Person Trips Per HH by No. of Autos/HH[c] | | | | % Average Daily Person Trips by Purpose[f] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | 1 | 2 | 3+ | 0 | 1 | 2 | 3+ | HBW | HBNW | NHB |
| 0-3 | 0.49 | 4.0 | 57 | 37 | 6 | 0 | 1.0 | 7.5 | 10.5 | 13.8 | 20 | 63 | 17 |
| 3-4 | 0.72 | 6.8 | 36 | 56 | 8 | 0 | 1.7 | 9.2 | 13.3 | 16.4 | 22 | 60 | 18 |
| 4-5 | 0.81 | 8.4 | 29 | 61 | 10 | 0 | 2.5 | 10.2 | 14.5 | 17.6 | 22 | 58 | 20 |
| 5-6 | 0.94 | 10.2 | 21 | 65 | 13 | 1 | 3.5 | 11.4 | 14.5 | 19.0 | 22 | 58 | 20 |
| 6-7 | 1.01 | 11.7 | 17 | 66 | 16 | 1 | 4.5 | 12.5 | 15.6 | 20.5 | 20 | 58 | 22 |
| 7-8 | 1.14 | 13.6 | 12 | 65 | 21 | 2 | 5.4 | 13.8 | 17.0 | 22.2 | 20 | 57 | 23 |
| 8-9 | 1.25 | 15.3 | 9 | 61 | 28 | 2 | 5.8 | 15.0 | 17.5 | 23.0 | 20 | 57 | 23 |
| 9-10 | 1.34 | 16.2 | 6 | 58 | 33 | 3 | 6.3 | 15.8 | 18.0 | 23.5 | 19 | 57 | 24 |
| 10-12.5 | 1.50 | 17.3 | 4 | 50 | 40 | 6 | 6.8 | 16.0 | 19.0 | 24.5 | 19 | 57 | 24 |
| 12.5-15 | 1.65 | 18.7 | 2 | 40 | 51 | 7 | 7.0 | 16.0 | 20.4 | 25.0 | 19 | 56 | 25 |
| 15-20 | 1.85 | 19.6 | 2 | 28 | 57 | 13 | 7.2 | 15.0 | 21.0 | 25.5 | 18 | 56 | 26 |
| 20-25 | 2.01 | 20.4 | 1 | 20 | 61 | 18 | 7.5 | 15.0 | 21.0 | 25.5 | 18 | 55 | 27 |
| 25+ | 2.07 | 20.6 | 1 | 19 | 59 | 21 | 7.5 | 15.0 | 21.0 | 25.2 | 18 | 55 | 27 |
| Wt. Avg. | 1.55 | 14.5 | 14 | 48 | 33 | 6 | 5.4 | 13.7 | 18.4 | 22.4 | 20 | 57 | 23 |

Source: (18)

Table 2.2 (Continued)

URBANIZED AREA POPULATION: 250,000-750,000

| IncomeRange 1970 $ (000's) | Avg Autos Per HH[d] | Average Daily Person Trips per HH[e] | % HH by Autos Owned[b] | | | | Average Daily Person Trips Per HH by No. of Autos/HH[c] | | | | % Average Daily Person Trips by Purpose[f] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | 1 | 2 | 3+ | 0 | 1 | 2 | 3+ | HBW | HBNW | NHB |
| 0-3 | 0.47 | 3.3 | 58 | 37 | 5 | 0 | 1.4 | 5.6 | 9.3 | 9.3 | 10 | 67 | 23 |
| 3-4 | 0.77 | 5.8 | 38 | 50 | 10 | 2 | 2.0 | 7.4 | 10.8 | 11.1 | 13 | 64 | 23 |
| 4-5 | 0.88 | 6.9 | 29 | 57 | 12 | 2 | 2.5 | 8.0 | 11.5 | 11.9 | 21 | 57 | 22 |
| 5-6 | 1.01 | 8.4 | 20 | 62 | 16 | 2 | 2.9 | 9.0 | 12.1 | 12.7 | 22 | 56 | 22 |
| 6-7 | 1.10 | 9.5 | 14 | 65 | 19 | 2 | 3.5 | 9.7 | 12.7 | 13.5 | 22 | 55 | 23 |
| 7-8 | 1.24 | 10.9 | 8 | 64 | 25 | 3 | 4.0 | 10.6 | 13.5 | 14.4 | 20 | 55 | 25 |
| 8-9 | 1.33 | 11.7 | 6 | 60 | 30 | 4 | 4.6 | 11.0 | 14.2 | 15.3 | 20 | 55 | 25 |
| 9-10 | 1.40 | 12.4 | 4 | 57 | 35 | 4 | 5.2 | 11.2 | 14.8 | 16.2 | 20 | 55 | 25 |
| 10-12.5 | 1.58 | 13.5 | 2 | 46 | 46 | 6 | 5.5 | 11.3 | 15.6 | 17.6 | 20 | 55 | 25 |
| 12.5-15 | 1.72 | 14.6 | 2 | 36 | 53 | 9 | 5.5 | 11.4 | 16.4 | 18.8 | 20 | 53 | 27 |
| 15-20 | 1.88 | 15.5 | 2 | 26 | 58 | 14 | 5.2 | 11.5 | 16.7 | 19.1 | 20 | 52 | 28 |
| 20-25 | 2.04 | 16.0 | 1 | 20 | 59 | 20 | 5.0 | 12.0 | 16.7 | 18.6 | 20 | 50 | 30 |
| 25+ | 2.08 | 16.2 | 1 | 17 | 61 | 21 | 5.0 | 12.0 | 16.7 | 18.6 | 20 | 50 | 30 |
| Wt. Avg. | 1.41 | 11.8 | 12 | 44 | 37 | 7 | 4.3 | 10.0 | 14.4 | 15.8 | 20 | 55 | 25 |

URBANIZED AREA POPULATION: 750,000-2,000,000

| IncomeRange 1970 $ (000's) | Avg Autos Per HH[d] | Average Daily Person Trips per HH[e] | % HH by Autos Owned[b] | | | | Average Daily Person Trips Per HH by No. of Autos/HH[c] | | | | % Average Daily Person Trips by Purpose[f] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | 1 | 2 | 3+ | 0 | 1 | 2 | 3+ | HBW | HBNW | NHB |
| 0-3 | 0.47 | 1.9 | 58 | 37 | 5 | 0 | 0.8 | 3.2 | 5.7 | 7.3 | 14 | 66 | 20 |
| 3-4 | 0.68 | 3.7 | 40 | 52 | 8 | 0 | 2.0 | 4.5 | 7.0 | 9.2 | 22 | 59 | 19 |
| 4-5 | 0.78 | 4.5 | 32 | 58 | 10 | 0 | 2.5 | 5.0 | 7.5 | 10.0 | 28 | 53 | 19 |
| 5-6 | 0.84 | 5.1 | 28 | 60 | 12 | 0 | 2.7 | 5.6 | 8.0 | 11.0 | 28 | 53 | 19 |
| 6-7 | 0.95 | 5.8 | 22 | 62 | 15 | 1 | 2.9 | 6.1 | 8.6 | 11.6 | 28 | 53 | 19 |
| 7-8 | 1.06 | 6.5 | 16 | 63 | 20 | 1 | 3.0 | 6.5 | 9.2 | 12.2 | 27 | 53 | 20 |
| 8-9 | 1.16 | 7.2 | 12 | 63 | 23 | 2 | 3.2 | 6.9 | 9.5 | 12.6 | 27 | 53 | 20 |
| 9-10 | 1.25 | 7.7 | 9 | 61 | 27 | 3 | 3.3 | 7.1 | 9.9 | 13.0 | 27 | 54 | 19 |
| 10-12.5 | 1.41 | 8.5 | 5 | 56 | 34 | 5 | 3.4 | 7.5 | 10.1 | 13.6 | 26 | 53 | 21 |
| 12.5-15 | 1.60 | 9.4 | 2 | 45 | 46 | 7 | 3.6 | 7.5 | 10.7 | 14.2 | 25 | 53 | 22 |
| 15-20 | 1.77 | 9.9 | 2 | 35 | 51 | 12 | 3.6 | 7.6 | 10.7 | 14.6 | 24 | 53 | 23 |
| 20-25 | 1.95 | 10.6 | 2 | 24 | 56 | 18 | 3.7 | 7.0 | 11.1 | 14.8 | 24 | 53 | 23 |
| 25+ | 2.02 | 11.0 | 2 | 20 | 58 | 20 | 4.0 | 7.0 | 11.3 | 14.8 | 23 | 54 | 23 |
| Wt. Avg | 1.31 | 7.6 | 15 | 48 | 32 | 6 | 3.1 | 6.5 | 9.5 | 12.6 | 25 | 54 | 21 |

- Table 2.3 contains trip production and attraction estimates by urban area population; i.e., for urban areas of different population categories, factors for determining external tripmaking levels, and relationships for determining trip attractions by purpose for analysis areas based on employment, retail activity, and population. The trip production and attraction estimates may be combined to produce a production-attraction matrix for use in the second step of the travel demand analysis procedure.

Trip distribution produces zone-to-zone tripmaking (trip interchange) estimates. A production-attraction matrix developed using Table 2.3 of the trip generation phase, or supplied by another source (such as previous travel demand estimation efforts), forms an estimate of the "size" of each zone. Interchange estimates are then based on this "zone size" and the ease of travelling between the zones, measured by a "friction factor" or "impedance."[1] The approach developed for manual estimation has been streamlined by:

- shortcut calculation of zone-to-zone impedance based on airline distance.
- a set of friction factor nomographs for four urban area sizes and three trip purposes (home-based work, home-based non-work, and non-home-based).
- simplified worksheets for calculating trip interchanges.

The only required inputs are a production/attraction matrix and a map of the study area for determining airline distances between zones. Manual calculations are expected to be manageable using this technique with up to 80 zones--a 34-zone distribution was conducted in under 26 person-hours.

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[1] See (5) for an in-depth discussion of the Gravity Model which provides the basis for this trip distribution procedure.

## TABLE 2 .3

## Trip-Generation Parameters

### PART A - TRIP PRODUCTION ESTIMATES

| Urbanized Area Population | Average Daily Person Trips Per HH[a] | % Average Daily Person Trips by Mode[b] | | | % Average Daily Person Trips by Purpose[a] | | | Auto Person Trips as a % of Total Person Trips[c] | | | Auto Driver Trips as a % of Total Person Trips[d] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Public Transit | Auto Passenger | Auto Driver | HBW | HBNW | NHB | HBW | HBNW | NHB | HBW | HBNW | NHB |
| 50,000- 100,000 | 14 | 2 | 40 | 58 | 16 | 61 | 23 | 96 | 99 | 98 | 70 | 54 | 68 |
| 100,000- 250,000 | 14 | 6 | 30 | 64 | 20 | 57 | 23 | 88 | 97 | 94 | 64 | 54 | 66 |
| 250,000- 750,000 | 12 | 8 | 31 | 61 | 20 | 55 | 25 | 84 | 96 | 92 | 62 | 54 | 64 |
| 750,000-2,000,000 | 8 | 13 | 30 | 57 | 25 | 54 | 21 | 74 | 93 | 86 | 56 | 53 | 60 |

### PART B - USEFUL CHARACTERISTICS FOR TRIP ESTIMATION

| Urbanized Area Population | External Travel Characteristics: % of Total External Trips Passing Through Area[e] | External Travel Characteristics: % of Total External Trips to the CBD[e] | Total Areawide Truck Trips as a % of Areawide Auto Driver Trips[f] |
|---|---|---|---|
| 50,000- 100,000 | 21 | 22 | 27 |
| 100,000- 250,000 | 15 | 22 | 17 |
| 250,000- 750,000 | 10 | 18 | 16 |
| 750,000-2,000,000 | 4 | 12 | 16 |

### PART C - TRIP ATTRACTION ESTIMATING RELATIONSHIPS[g]
### (All Population Groupings for either Vehicle or Person Trips)

**TO ESTIMATE TRIP ATTRACTIONS FOR AN ANALYSIS AREA, USE:**

$$\text{HBW Trip Attractions} = F_1\left[1.7\,(\text{Analysis Area Total Employment})\right]$$

$$\text{HBNW Trip Attractions} = F_2\left[10.0\begin{pmatrix}\text{Analysis Area}\\\text{Retail}\\\text{Employment}\end{pmatrix} + 0.5\begin{pmatrix}\text{Analysis Area}\\\text{Non-Retail}\\\text{Employment}\end{pmatrix} + 1.0\begin{pmatrix}\text{Analysis Area}\\\text{Dwelling}\\\text{Units}\end{pmatrix}\right]$$

$$\text{NHB Trip Attractions} = F_3\left[2.0\begin{pmatrix}\text{Analysis Area}\\\text{Retail}\\\text{Employment}\end{pmatrix} + 2.5\begin{pmatrix}\text{Analysis Area}\\\text{Non-Retail}\\\text{Employment}\end{pmatrix} + 0.5\begin{pmatrix}\text{Analysis Area}\\\text{Dwelling}\\\text{Units}\end{pmatrix}\right]$$

Where: $F_1$, $F_2$ and $F_3$ are areawide control factors.

**TO DEVELOP AREAWIDE CONTROL FACTORS, USE:**

$$F_1 = \frac{\text{Areawide Productions for HBW Trips}}{1.7\,(\text{Areawide Total Employment})}$$

$$F_2 = \frac{\text{Areawide Productions for HBNW Trips}}{\left[10.0\begin{pmatrix}\text{Areawide}\\\text{Retail}\\\text{Employment}\end{pmatrix} + 0.5\begin{pmatrix}\text{Areawide}\\\text{Non-Retail}\\\text{Employment}\end{pmatrix} + 1.0\begin{pmatrix}\text{Areawide}\\\text{Dwelling}\\\text{Units}\end{pmatrix}\right]}$$

$$F_3 = \frac{\text{Areawide Productions for NHB Trips}}{\left[2.0\begin{pmatrix}\text{Areawide}\\\text{Retail}\\\text{Employment}\end{pmatrix} + 2.5\begin{pmatrix}\text{Areawide}\\\text{Non-Retail}\\\text{Employment}\end{pmatrix} + 0.5\begin{pmatrix}\text{Areawide}\\\text{Dwelling}\\\text{Units}\end{pmatrix}\right]}$$

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Source: (18)

Mode shares can be predicted for two modes: auto and transit. No provision for estimating carpooling activity is incorporated into the procedure. For each origin-destination pair, three steps are required to determine the share of trips made by transit and auto:

- Determine auto impedance--auto impedance is treated as a function of airline distance, average operating speed, parking cost and auto operating cost per mile. A set of nomographs is provided for determining zone-to-zone auto impedance.
- Determine transit impedance--transit impedance is a function of fare, airline distance (which must be adjusted if a transfer is involved in making the trip), and access mode (auto or walk). Two nomographs (for the auto and walk access modes) are provided for determining transit impedance.
- Determine transit mode share--based on the impedances for trips between each zone pair by both transit and auto, determine the transit mode share. Nomographs are provided for home-based work, home-based non-work, and non-home-based trips.

Several rules of thumb (based on current experience in the transit industry) for determining transit patronage are also included for quick estimation purposes.

In order to conduct the mode choice analysis, the following items are required:

- An area map for determining airline distance between zones
- A map of the existing or proposed transit system for use in determining transit airline distance (taking into account necessary transfers)
- Transit fares
- Estimated auto operating costs per mile
- Average zone-to-zone highway speeds, which may be determined using nomographs (based on airline distance, urban area population, and percent of freeway and arterial mileage travelled between zones) or knowledge of the study area.

Because this procedure uses distances rather than travel time, it cannot be used to evaluate the impact of transit headway changes. However, an alternative approach for determining impedance for the transit mode which does incorporate travel time is provided; impedance may be determined by the following equation:

$$I_T = IVTT + 2.5\ OVTT + \frac{FARE}{1/3\ HHI}$$

where:

$I_T$ = Transit impedance

IVTT = In-vehicle travel time

OVTT = Out of vehicle travel time (wait time)

FARE = Transit fare

HHI = Household income

This impedance measure then could be used to examine transit mode shares under various operating policies.

The traffic assignment procedure involves forecasting passenger and vehicle volumes on the transportation system given the results of the previous modelling steps. Three levels of traffic assignment capability are provided in the procedure:

- Traditional traffic assignment
- Traffic generation and decay
- Traffic diversion and shift

The traditional traffic assignment methodology is the common "all or nothing assignment" process: all traffic between two zones is assigned to the shortest path available. In order to keep the analysis manageable, the number of zone-to-zone interchanges must be kept relatively small. A technique for determining turning movements also is incorporated into the traditional methodology.

Traffic generation and decay is used to analyze a specific traffic generator and its effects on the nearby street network. Average street volumes are read from one chart, and the volumes due to the proposed traffic generation (e.g., a shopping center) are added to the base volume according to the following characteristics of the generator:

- Density and size
- Level of service
- Auto ownership
- Transit availability
- Residential/non-residential mix
- Freeway diversion factors

Traffic diversion and shift is a simple and quick methodology which enables the user to determine the effects of changes in highway level of service on highway segment volumes. Traffic diversion due to improvements on a facility is an example of the type of impact analysis capability provided by the diversion and shift graphs.

Two additional information sources related to travel demand estimation are provided in the procedures--current average automobile occupancy characteristics and current average time of day characteristics. Sets of tables are provided which relate auto occupancy and the time distribution of travel to urban area size, trip purpose, land use characteristics and other factors. These averages, however, are not responsive to policy measures designed to affect ridesharing activity or the hourly distribution of travel.

Suggested Applications--The set of quick response techniques would be most useful for:

- the development of "base case" data if this information is not available from other sources for given urban area
- adjustment of available base data to represent a future analysis year, taking into account planned development projects and urban growth patterns
- traffic volume impact analysis of specific site developments and expected residential growth pattens.

The method is not fully satisfactory for:

- analysis of measures designed to encourage shifts from single-occupant autos to the transit and shared ride modes.

If the route choice and traffic volume impacts of a particular measure are of interest, the manual pivot-point analysis could be used in place of the mode choice analysis procedure provided in this set of procedures.

Case Study III in Volume II shows the use of these procedures as part of the process of specifying a base case for an urban corridor analysis.

### 2.1.3 Systematic Data Analysis--Overview

Several procedures in common use for estimating both base case transportation conditions and probable impacts are described below. These procedures do not forecast with the accuracy of the methodologies discussed previously, and they rely to a greater degree on the judgment of the analyst. However, they usually require fewer data than the methods described above; and some of them can provide the kind of information that many decision-makers request--evidence of what happened elsewhere or what local conditions are, for example. The procedures should be used with care, since they rely on the accuracy of assumptions of similarity or correlation. They may be best suited to preliminary feasibility studies and other situations where a great degree of precision is not required. There also are instances when constraints on time, data, labor and/or funds will dictate the use of these simple approaches.

Approaches of this type are discussed in this section under the following headings:

- Transfer of travel characteristics and elasticity data
- Inference from previous studies or applications
- Analysis of urban area data

### a. Transfer of Travel Characteristics and Elasticity Data

Analysts often find that data needed to study a proposed transportation measure are unavailable or are so old that they are unreliable. When new data collection is impractical, a common solution is to use data compiled in another area or averaged over several areas. Such data as average auto occupancy, household auto ownership levels for various socioeconomic groups, and trip frequency by trip type and household characteristics are typical of those that might be "borrowed" in this fashion (See Section 3.1.3). Elasticities of travel demand, e.g., the percent change in transit ridership in response to a 1 percent change in fare or the percent change in VMT in response to gas price, are a special type of data whose transfer frequency is considered; the elasticities may have been determined through observation or may have been estimated in a model.

The reliability of such transferred data depends on how similar certain socioeconomic conditions and other factors are from one location to the other. Factors which normally affect travel behavior, such as population, income, auto ownership, and land use patterns, can cause travel characteristics and elasticities to vary, and the validity of any transfer of data between sites will depend on the degree to which variations in these conditions can be controlled. In general, transferred data are more likely to be valid if the locations have similar population, land use, and auto ownership characteristics.

Chan suggests that data should be transferred only between cities of the same "category," where cities are categorized in a fashion which should minimize within-category variation in travel behavior (7). The proposed classification divides cities into four categories by population and spatial structure, characteristics which are associated with travel demand patterns and the kinds of transportation systems which are available. The categories are:

- Large (population over 800,000)/multi-nucleated
- Large (population over 800,000)/core-concentrated
- Medium (50,000-800,000)/multi-nucleated
- Medium (50,000-800,000)/core-concentrated

Research indicates that trip frequencies and trip lengths tend to be greater in large cities. However, auto ownership per household and the share of total trips by auto tend to be greater in small cities. Empirical evidence suggests that multi-nucleated cities generally have lower levels of total travel activity, as measured in vehicle miles of travel, than core-concentrated cities of equivalent size, since the dispersion of activity centers tends to result in shorter average trip lengths between residential, employment, and other locations.

Suggested Applications--The transferred data or elasticities generally should be used only at a fairly large geographical scale of analysis (i.e., city or areawide) because they are not accurate enough for use in the assessment of a small-scale transportation improvement. For example, a transferred elasticity could be used to produce a rough estimate of the systemwide change in transit patronage resulting from a fare increase, but it would be inappropriate in most cases for forecasting the effects of individual transit route changes. Transferred data may be of particular use in "first-cut" or "initial screening" analyses. Case Studies I and II in Volume II show the use of transferred data to define base conditions for studies of an urban highway corridor and an auto-restricted zone.

### b. Inference from Previous Studies or Applications

Most of the measures which are being proposed in transportation/air quality planning already have been studied and/or implemented somewhere. One way of evaluating such measures is to look into the results of such previous studies or applications and extrapolate their findings to the situation currently under study.

The validity of drawing such inferences will depend on the similarity of conditions between the two sites. Differences in conditions or characteristics which influence transportation behavior, particularly socioeconomic and spatial characteristics, could result in the same measure having markedly different results in different locations. Since it is extremely difficult, if not impossible, to fully control for the difference among areas, one should be cautious in drawing conclusions based on extrapolated findings. Nevertheless, careful study of the literature can prove insights into the probable impacts of a measure, particularly if a wealth of experience exists or if less extensive experience has been remarkably consistent. It generally should be possible to base qualitative statements about likely impacts on a review of earlier findings, and sometimes order-of-magnitude/quantitative conclusions can be drawn.[1]

Suggested Applications--This approach might be used at a preliminary stage of analysis to obtain a general indication of the appropriateness of a measure. However, depending on the quality and detail of the literature available on the measure under consideration, the information obtained from review of previous studies or applications could serve as a guide for some quantitative analysis using available local data. The detail and accuracy of the resulting estimates will not equal those obtainable using some of the methods previously described, which suggests that this type of analysis should be confined to preliminary analyses where precision is not critical.

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[1] A useful reference summarizing the results of previous applications is provided by (55). A guide to further references by measures is also provided.

This approach may also be useful for evaluating programs which are difficult to analyze with other manual techniques, e.g., bicycle policies.

### c. Analysis of Urban Area Data

Data specific to the area under study can be of great value, particularly when home interview surveys are outdated or insufficient. The U.S. Census publishes data on modal shares, median distance, and median trip time for work trips for 60 SMSA's, 20 of which are surveyed each year on a rotating basis. Most MPO's have at least some data on hand which could be used to estimate both work and non-work trips--ranging from modal forecasts to cordon counts, small-area surveys, and other limited-scope data.

Such data can be used to estimate current and future base case conditions, and analysis of urban area data can help to identify appropriate target areas or "markets" for various measures. When used in conjunction with some knowledge or reasonable assumptions about the effects a proposed measure might have, data analysis can provide a quick first-cut policy analysis.

Suggested Applications--Data analysis is useful:

- for preliminary feasibility analyses
- when available data are insufficient to use worksheets
- when worksheets cannot easily be adapted for analysis of the particular measures under consideration

Case Studies I and II in Volume II show the use of available urban area data to define base conditions for the analysis of an urban highway corridor and an auto-restricted zone. Also, Section 5.5 discusses the sources of urban area data in greater detail.

Table 2.4 illustrates how trip generation data, in combination with assumptions on mode share potential, can be used to assess the potential impacts of new bicycle facilities (3). The analysis illustrated in the

## TABLE 2.4

## Daily Home-Based Vehicular Trips that Might Be Attracted to the Bicycle[1]

| Trip Purpose | Total Number of Daily Home Based Vehicular Trips | Percentage of Vehicular Trips Less Than 6 Min. in Duration | Assumed Percentage of Vehicular Trips Less Than 2 miles in Duration That Might Be Made by Bicycle | Resultant Percentage of All Vehicular Trips Attracted to the Bicycle | Number of Vehicular Trips That Would Be Attracted to Bicycle Use If Proper Facilities Were Provided | Percent of Total Bicycle Trips |
|---|---|---|---|---|---|---|
| School | 160,000 | 21.1%(2) | 50.0% | 10.0%(2) | 16,000 | 6% |
| Recreation | 917,000 | 35.0% | 35.0% | 12.0% | 100,000 | 37% |
| Personal Business | 666,000 | 40.5% | 30.0% | 12.0% | 81,000 | 30% |
| Shopping | 366,000 | 48.6% | 20.0% | 9.7% | 55,000 | 21% |
| Work | 829,000 | 18.9% | 10.0% | 2.0% | 16,000 | 6% |
| Medical | 48,000 | 14.0% | 5.0% | 0.7% | —(3) | 0% |
| Total | 3,086,000 | | | 8.7% | 268,000 | |

Source: "A Summary Report of Travel in the Twin Cities Metropolitan Area" (Draft Report), Twin Cities Metropolitan Council.

(1) Based on 1970 Minneapolis/St. Paul trip data.

(2) Low percentages in this category are due to the high percentage of pedestrian trips which are not counted as vehicular trips.

(3) Less than 1000 trips.

Reproduced from best available copy.

Source: (3)

table forecasts the number of daily bicycle trips which might occur in the Minneapolis/St. Paul metropolitan area if proper facilities were provided. Actual data on trip frequencies and distances are used to determine the number of daily trips shorter than two miles. Of these trips, it is assumed that a certain percentage, specified by purpose, may be attracted to the bicycle mode.

## 2.2 Programmable Calculator Methods

Calculator programs are an adaption of manual methods of analysis. While calculator methods do not represent a methodological advancement, there are advantages in the use of calculator programs which make them a powerful innovation:

- Data collection and preparation will be essentially the same whether a manual approach or a program is used; but use of a program does away with the time to set up and repeat the calculation steps. This time savings can be spent in collecting more data, testing variations of the proposed measures, and analyzing impacts on additional "market segments" or population subgroups. The programs thus allow the analysis to be more detailed, without increasing costs or effort.

- Calculator methods can be less expensive than either manual methods (by saving staff time) or computer methods (by avoiding computer use). Progammable calculators without a "carry-over memory", i.e., a capability of storing a program indefinitely, cost as little as $100 for 100 program steps and 20 memory locations. In the intermediate price range ($200-$500) storage capabilities are sometimes available within the calculator itself, and capacities range up to 960 program steps or 100 memory locations (with a tradeoff of eight program steps for each memory location). Magnetic card programmable calculators will store a program in "hard copy" indefinitely, without dedication of program space in the calculator; prices currently start at about $250. Whichever programmable calculator is chosen, its cost should be recovered in a short time by the value of time saved in performing transportation measure analyses. In addition, the calculator can be used in other work.

- Calculator methods provide results with greater precision, since none of the intermediate calculations are rounded. This is a small consideration, since the input data are likely to be estimates, but it could make a difference when similar policies are compared.

- It is not necessary to have special training or in-depth understanding of the methdology to use the calculator programs. (This is also true of some manual methods.) Worksheets with detailed instructions allow junior staff members to complete analyses after they have been set up by analysts familiar with the selected technique. Thus, planning agencies which elect to use calculator program methods will not need to invest in extensive staff training.

- Compared to computer methods, calculator programs require less data collection and preparation, and they obviously avoid the need for computer facilities, a programmer's time, and a computer time budget. However, their capabilities are limited in comparison to computer-based techniques, and they may not provide enough detail for analyses of certain policies or market segments. It nonetheless may be appropriate to use the faster, cheaper calculator programs to analyze a large number of measures, to focus on a particular market segment, and to refrain from computer use until a smaller number of alternatives deserving more detailed analysis are selected.

The calculator programs described here cover a range of transportation and air quality analysis requirements but the list is by no means comprehensive. New programs, or modifications to available programs, can be developed quite easily in response to available input data, analysis needs, or output requirements.

The types of calculator programs available for demand analysis include:

- mode choice models: a number of mode choice models are available (48); some provide estimates of base case mode shares while others are simply calculator versions of the worksheet pivot-point methods. Descriptions of two programs are included in this section.

- trip table estimation: programs for estimating base case trip tables either by mode or for total person-trips also are available. Programs have been developed for three commonly used trip distribution models (gravity, intervening opportunities, and competing opportunities) though the methods are limited to about 15 zones (52). Programs based on the Fratar growth factor method for adjusting trips between zones based on growth rates in each zone have also been developed (52). A calculator program for developing a transit trip table from boarding and alighting counts is also available (48).

- generation of household samples: a program is available to generate a sample of households for use in the mode choice models described earlier (44). The program uses published tract and block level reports from the U.S. Census to provide information on such household characteristics as average household size, income, and auto ownership.

Three calculator programs--two mode choice models and a method for generating household samples--are described in the sections which follow.

### 2.2.1 Program HHGEN--Developing a Sample of Households (48)

Socioeconomic statistics for a residential area usually do not illuminate the variations from the average which may be of particular importance in impact prediction. It is sometimes desirable to forecast the impacts of transportation system changes on a sample of households so that variations in response can be examined. This sample may be provided by a typical home interview survey; however, an up-to-date survey may not be available, or available survey results may not adequately represent the particular group which would be impacted by a proposed measure (e.g., households living near a proposed new bus route).

HHGEN may be used to develop a "synthetic" sample of households from tract and block data provided by the decennial U.S. Census. An adjustment procedure allows the household characteristics to be updated if necessary, using data more recent than the Census. The household sample generation methods used in HHGEN represent initial, illustrative approaches applicable using programmale calculators. Research is continuing at MIT, where HHGEN was developed, to devise improved methods of using programmable calculators in this way.

Related manual techniques for synthesizing work locations and the number of licensed drivers for each household also are documented. This set of households may then be used in conjunction with the manual disaggregate demand forecasting techniques to determine base condition travel behavior within the study area, as well as future behavior in response to transportation system or other changes. The results developed using the household sample are then scaled up to represent the entire study area population. Case Study III in Volume II illustrates a typical analysis using HHGEN in conjunction with calculator travel demand forecasting techniques.

Calculation Procedure--The household generation process within HHGEN is sequential, assigning to each household the following characteristics:

- household type (family/unrelated individual)
- housing type (single family/multi-family)
- housing tenure (rent/own; families only)
- number of workers (0/1/2/3+)
- income (dollars per year)
- family size (2,3,4...)
- number of autos (0,1,2+)

The input data required by HHGEN are available from the following tables provided by the Census:

- Characteristics of Housing Units and Population by Blocks (County)
- Income Characteristics of the Population--Tract Level (SMSA)
- Structural, Equipment, and Financial Characteristics of Housing Units--Tract Level (SMSA)

Both tract and block data may be used, but data at the block level of detail may be omitted if this level is not required. The following input data items are required for Census tracts:

- Total population
- Percent living in group quarters
- Number of single family houses
- Average value of owner-occupied units
- Number of rental units
- Average rent
- Number of single-person households
- Number of households with roomers, boarders, or lodgers
- Mean family income
- Median unrelated individual income
- Number of households owning 1, 2, and 3+ autos

Block level data (if used) includes:

- Population
- Percent in group quarters
- Number of single family houses
- Number of owner-occupied units
- Average value of owner-occupied units
- Number of rental units
- Average rent
- Number of single-person households
- Number of households with roomers, boarders, or lodgers

The only other input data item required is the number of households which are to be generated, which is specified by the user based on the total number of census blocks to be represented, the desired accuracy of the forecasts developed using the household sample, and the budget and analyst time available for the analysis. In general, the greater the number of households generated, the more accurate the forecasts developed will be. However, manual or calculator forecasting on a very large sample of households can be quite time consuming and tedious. For most applications, a sample of 1000 should be sufficient, and a sample of a few hundred is enough for many problems.

The program HHGEN, using the above data items, develops a set of households, each with specific auto ownership levels, income, housing type and tenure, etc., reflective of the average and frequency statistics reported by the Census. Many of the characteristics are determined using Monte Carlo methods in which the value of a given characteristic is selected at random from a distribution which reflects the probabilities of each value occurring. Some characteristics are determined contingent on the values of previous characteristics. For example, auto ownership is a function of income and housing. Should the number of licensed drivers or workplace be of interest, simple manual techniques employing similar Census or other information have also been designed.

Runs of HHGEN are repeated for each Census block or tract within the study area to develop a set of households representing that area.

Suggested Applications--Because of its orientation to Census blocks and tracts, HHGEN is best suited to the analysis of actions within a relatively limited study area; HHGEN is particularly useful in the analysis of alternative transit services and routings within a specific area or corridor, as illustrated in Case Study III. In conjunction with a synthetic disaggregate demand model, HHGEN may be used to develop base data when current travel behavior is not known.

HHGEN is not well suited to areawide analysis, for which a home interview survey would be a more appropriate source of a sample of households. The number of calculation steps required can be quite cumbersome when the technique is used in areawide analysis or when a wide variety of measures are being explored. When using manual or calculator approaches to do such areawide or wide-ranging analyses, average statistics for more aggregate groupings of the population are more practical than those which employ a random sample of households; these averages can be used to obtain comparatively accurate forecasting with much less effort.

### 2.2.2 Program 2MODE-AGG--Synthetic Mode Choice

This program uses the multinomial logit model to predict, for sample individuals representative of market segments (e.g., income levels, auto ownership levels, etc.), the probability of choosing one of two modes (auto and transit) for the work trip. The choice probabilities are then multiplied by the population for each market segment to yield aggregate modal volumes. The sample individuals' socioeconomic (auto ownership level and income) and trip level-of-service characteristics (trip distance, and travel time and cost for each mode) are used to predict mode choice probabilities. Any number of market segments may be used in the analysis, the number depends on the level of data detail available and the level of accuracy and detail desired in the analysis. The model within 2MODE-AGG is of the synthetic type and therefore may be used to develop estimates of existing travel behavior if this information is not available.

Calculation Procedure--Program 2MODE-AGG is designed for use with a magnetic card programmable calculator. Base data for each representative individual or market segment is recorded on magnetic cards, along with the coefficients of the travel demand model to be employed. Default model coefficients are also supplied.

The required data for each individual or market segment includes:

- household income
- household auto ownership
- number of licensed drivers in household
- work trip origin and destination.

Trip data, recorded for origin-destination pairs, includes:

- in-vehicle travel time for auto and transit
- out-of-vehicle travel time for auto and transit
- out-of-pocket travel cost for auto and transit
- trip distance.

All data items are recorded on magnetic cards and then run through the calculator program which reports total volumes for auto and transit. A set of worksheets for organizing the necessary input data also has been developed. Any number of market segments or representative individuals may be used in the analysis. A potential source of a set of representative households is the use of Program HHGEN described previously.

Suggested Applications--The most effective use for 2MODE-AGG is in developing base case mode split data for auto and transit. Its usefulness for air quality planning is limited by the restriction to two modes, however. In order for the output of the program to be useful for policy analysis, an independent estimate of ridesharing activity would have to be developed. A particularly attractive application of 2MODE-AGG is the analysis of specific transit service proposals within a limited corridor or service area, as shown in Case Study III, Volume II. In combination with program HHGEN, the program can be used to develop estimates of transit service patronage in areas where no transit service currently exists.

When base conditions have been determined using 2MODE-AGG, it is fairly easy to apply the technique for forecasting the impact of program measures designed to encourage transit use. Carpool promotion, high-occupancy vehicle lanes and other ridesharing incentives cannot be analyzed using 2MODE-AGG, however. Despite the relative ease of using the program for policy analysis once base conditions have been determined, it may be even easier to employ a pivot-point model such as 3MODE(AGG)-VAN or the manual pivot-point worksheets, because both have more modest input data requirements.

Because of the model's limitation to the analysis of two modes and its requirement for socioeconomic data for each market segment or representative household, if base modal shares are known, policy analysis may be more effectively carried out using the incremental pivot-point worksheets or 3MODE-AGG(VAN). These techniques afford the analyst greater flexibility and acuracy in program measure impact analysis while requiring less data.

### 2.2.3 Program 3MODE(VAN)-AGG--A Pivot-Point Mode Choice Model[1]

This program is designed to calculate revised work trip mode shares for up to four modes, including vanpool. It can be used to analyze an unlimited number of market segments and to aggregate the results for all segments to produce areawide average mode share and vehicle miles of travel impacts resulting from the policy being analyzed.

The program is based on the generalized multinomial logit model of work trip mode choice identical to that used in the Manual Pivot-Point Worksheets. The program incorporates the specification and coefficients of a model developed using 1968 Washington, D.C. data (5). It is also possible for the user to insert coefficients from a locally estimated model and the program can adapt to models with a variety of specifica- tions. Extra storage capacity for model coefficients allows this flexibi- lity in the form of the specific model used in the program.

3MODE(VAN)-AGG extends the demand estimation programs found in (48) to include procedures for analyzing the demand for ridesharing modes. Procedures are available within the program to predict the mode shifts resulting from policies with differential impacts on carpools of varying size. Most frequently, these procedures would be used to determine the carpool size impact of policies including special incentives for the formulation of large carpools, such as high-occupancy vehicle lanes limited to vehicles with a specified minimum number of occupants.

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[1] See Appendix C for a complete program listing and detailed documentation for 3MODE(VAN)-AGG.

The calculator program is based on the pivot-point or incremental form of the logit model. It predicts new mode shares and vehicle-miles of travel based on existing shares and estimated changes in transportation level of service. For this reason, the data requirements for 3MODE(VAN)-AGG are modest compared to those of the 2MODE-AGG program.

Calculation Procedure--3MODE(VAN)-AGG as listed in Appendix C is designed for implementation on the Texas Instruments TI-59 calculator and its companion printer. The program may be stored on magnetic cards once it has been entered into a calculator.

The analyst identifies any number of market segments for analysis and the program determines the impacts on each segment separately. The results for each market segment are printed and then combined with previous market segment results. At any point in the analysis, the aggregate results up to that point can be printed for later review. Through careful ordering of the market segments to be analyzed, the impact of the measure under analysis can be examined for varying levels of aggregation of the population. Thus, for a regionwide policy aimed at increasing ridesharing, the impacts on CBD workers with and without access to transit, all CBD workers as a group, all central city workers, and all workers in the region can each be printed by 3MODE(VAN)-AGG.

The input data required by the program varies, depending on the policy under analysis. In the following list, all items not classified as optional are always required. The optional items are required for some calculator options:

- average round trip length
- annual household income (optional)
- average carpool size
- market segment size (population)
- average vanpool size (optional)
- vanpool circuity factor (extra distance for picking up passengers--optional)
- base work trip mode shares
  - drive alone
  - carpool
  - transit
  - vanpool
  - other
- changes in transportation level-of-service for each mode
  - in-vehicle travel time
  - out-of-vehicle travel time
  - out-of-pocket cost

Figure 2.2 illustrates the data flows within the program.

Default values based on national averages are provided for some of the input data items for use when local values are unavailable. A set of worksheets (included in Appendix C) has been developed to aid in the organization of the input data for each market segment, and in the execution of the program.

Suggested Applications--The program is applicable to the analysis of any transportation-air quality measure intended to affect the demand for alternative transportation modes. Because of the flexibility in analysis detail which it provides, the program can be used for broad assessments of the relative attractiveness of a large number of measures, or quite detailed evaluations of the mode choice and VMT impacts of a more limited set of measures. The program is particularly useful for the analysis of

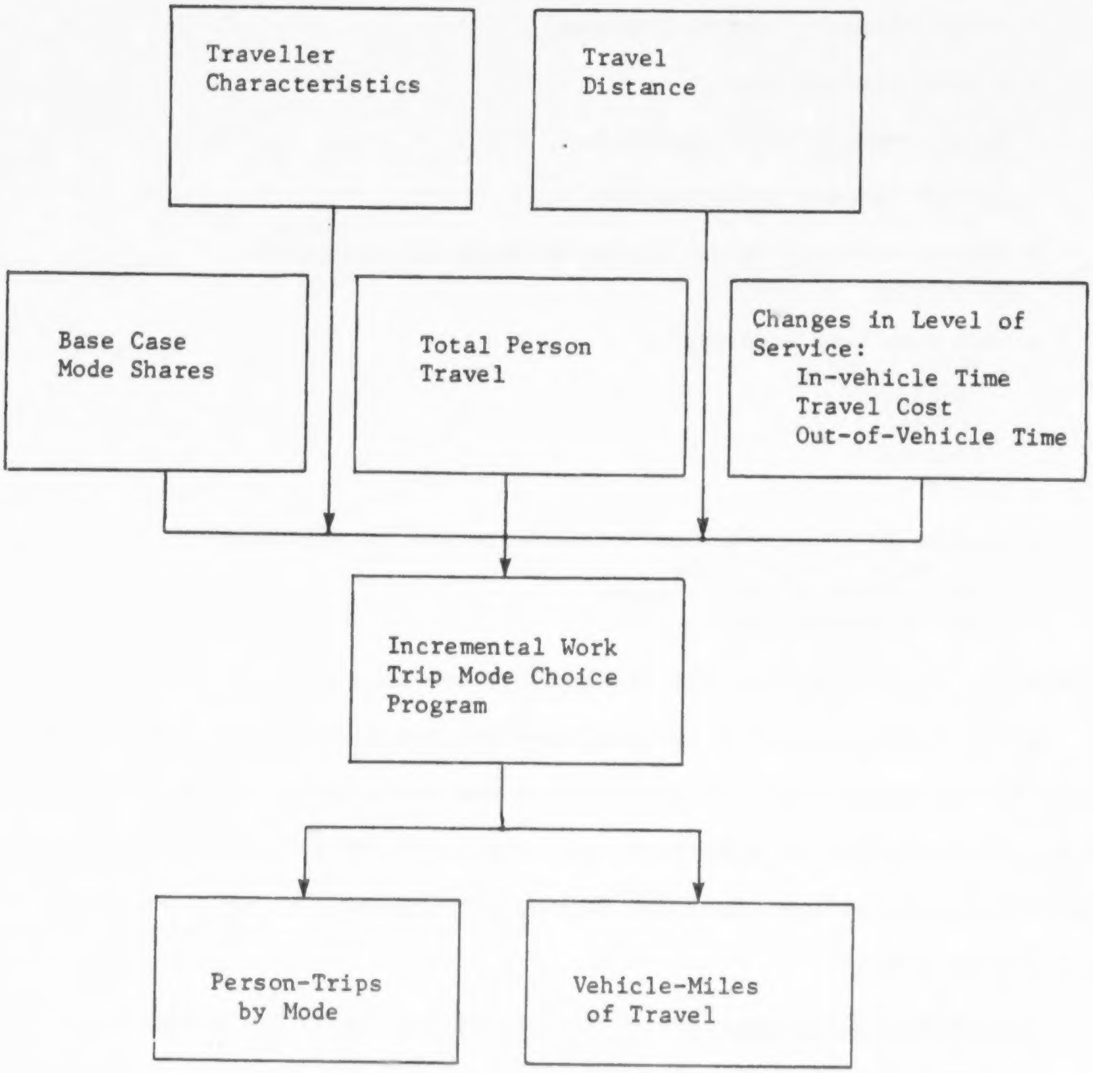
Traveller Characteristics
Travel Distance
Base Case Mode Shares
Total Person Travel
Changes in Level of Service:
In-vehicle Time
Travel Cost
Out-of-Vehicle Time
Incremental Work Trip Mode Choice Program
Person-Trips by Mode
Vehicle-Miles of Travel

FIGURE 2.2

Data Flows in Program 3MODE(VAN)-AGG

measures to encourage carpooling and vanpooling, since many other available techniques cannot accurately represent the impacts of such measures. Case Studies II and III in Volume II show the use of the program to analyze auto-restricted zone and transit corridor alternatives.

With minor modifications, involving the application of user-supplied coefficients to the demand model, the program can be used to analyze non-work as well as work travel impcts. Case Study III in Volume II provides an example of the use of 3MODE(VAN)-AGG in analyzing non-work travel impacts.

The use of the program is limited only by the availability of base case data to support an analysis using the pivot-point technique. The travel behavior (particularly mode shares) as well as the socioeconomic characteristics of each market segment must be known or estimated. The quality of the base case data can have an important effect on the accuracy of the resulting analysis.

## 2.3 Computer Methods

Like all sketch planning methods, computerized sketch planning techniques involve a certain degree of simplification in some aspects of the analysis. However, their use allows more detailed and complex analysis than would be feasible with manual or calculator techniques. The price of these improvements is a larger investment in trained staff, data, and computer resources.

For the most part, detailed urban transportation planning models are based on a four-step process for predicting travel demand:

- *Trip generation models* based on regressions or cross-classifications of trips by purpose against zonal characteristics such a number of dwelling units, household income, and number of employees.

- *Trip distribution models*, generally of the gravity type, in which the attractiveness of each potential destination is based on a log-linear function of the zone's attraction characteristics and its accessibility. These models predict trip destinations, given the trip ends predicted in the trip generation process.

- *Mode split models* which predict the fractions of trips by mode. These models are generally share models, used to estimate the fraction of total trips using a particular mode based on the "utility" of that mode and all alternative modes.

- *Traffic assignment methods* which assign trips to links in the transportation network based on all-or-nothing assignment to minimum travel time paths. Often the ability to apply iterative capacity restraint (to attempt to balance facility volumes and travel times) also is provided.

A variety of computer-based sketch planning approaches are available which address all or some of the steps of the process outlined above. *Aggregate* approaches use *average characteristics* of the population residing in a geographic area (i.e., a "zone"), such as average income per household, average household size, etc., to predict the travel behavior of a group (e.g., total trips per zone). Disaggregate approaches use individual observations and predict individual behavior--i.e., they predict the behavior of an individual (a person, a household) based on the characteristics of that particular individual. Such individual predictions then must be "factored up" to obtain a prediction of areawide, or population-wide, travel behavior. A number of approaches represent a combination of aggregate and disaggregate techniques. For example, model coefficients may be developed using disaggregate data but the model may then be applied using aggregate, or zonal average data.

A number of aggregate sketch planning systems have been developed which replicate this four-step process, but at a lower level of detail. These systems qualify as sketch planning tools either because their packaging and structuring makes them relatively easy to use, or because they can be used for large-zone (or district-level) analyses, or in most cases, both. Many of them are based on UMTA's Urban Transportation Planning System (UTPS) (71,72) which is not itself a sketch planning tool. SNAP (35), TAP (33), TASSIM (37), and TRIMS (50) fall into this group. COMPACT (46) and IMPACT (65) are similar systems developed in England which, while not UTPS-based, do incorporate the four-step prediction process.

Another set of methods, including CRISTAL (62) and TRANS (75), is based on aggregate travel demand models, but uses idealized city structures rather than detailed zonal systems and networks. This simplification greatly reduces analysis preparation costs and computer running times, but it also limits the method's ability to be sensitive to localized transportation system changes.

Most (if not all) of the aggregate sketch planning model systems are applied at a higher level of geographic aggregation than their more detailed counterparts. TRIMS (50), for example, is used to predict travel for the Washington, D.C. metropolitan area based on 150 "districts," as compared with the 1,250 "zone" system used for more detailed analysis. Savings in computer costs with higher levels of aggregation can be significant, particularly for calculations involving zone-to-zone matrices: A data matrix at the 150 district level would have 150 x 150, or 22,500 elements; zonal level matrices would have 1,250 x 1,250, or 1,562,500 elements.

The loss of detail inherent in highly aggregate approaches sometimes makes them inappropriate for analyzing certain transportation measures, because the aggregation may make it difficut or impossible to represent the differences in the transportation system before and after a measure is implemented. As an example, consider changes in parking charges in a small area within the CBD. If the zone in which the changes occur is very large, these changes will have an insignificant effect on zonal average charges. The model system then cannot predict the impact of the changes, unless its zone system can be tailored to the specific problem being analyzed.

Some aggregate model systems allow the simultaneous use of different levels of aggregation over different areas. It is possible to "window in" on a particular sub-area by using a detailed zone system to represent it, while using more aggregate zones (districts) for the remainder of the area. For example, TAP (33), as it is currently set up in the Dallas/ Fort Worth area, can use 40 districts, more than 6,000 zones, or any combination of districts in some areas and zones elsewhere. By allowing detailed analysis of selected areas, these windowing techniques retain much of the accuracy associated with more detailed model systems where such accuracy is most important, while achieving cost savings compared to those realized by other sketch planning models.

Another major simplification found in most sketch planning procedures based on aggregate model systems is a lower level of detail in network representation of the transportation system. In TRIMS (50), for example, the district level highway network is composed of principal arterials only, and a simplified transit network is used which is coded essentially as a highway network, with separate wait times at each origin district for trips destined to each of three separate areas (i.e., CBD, fringe, suburbs). In TASSIM (37), a "spider" network is used which represents the highway system by aggregating links between district pairs into a composite link. With this procedure, only 582 links are used to represent a network which at the most detailed level consists of 18,000 links. Similar problems to those associated with large zone systems can arise when coarse networks are used to analyze very localized transportation measures. However, those procedures which have the "windowing" capacity described earlier usually allow network components, specified at different levels of detail, to be used in a single run.

Computerized sketch planning techniques often place more emphasis on transportation system evaluation than the model systems designed for more detailed analysis. SNAP (35), for example, incorporates modules which generate a range of cost, consumer surplus, accident, air and noise pollution, accessibility, and community impact measures in easily-obtained matrices based on the groups impacted and the mode of travel.

The omission of a number of important variables from the traditional aggregate models may limit their usefulness in analyzing policies affecting certain kinds of transportation policies. For example:

- Trip generation models rarely include variables representing the amount or quality of transportation serving the various zones. Thus, the number of trips predicted to originate in each zone is unaffected by changes in the transportation system characteristics. This usually is acceptable for work trips, which (at least in the short term) mostly must be made regardless of any changes in the transportation system. But for the more discretionary trip purposes such as shopping or personal business, the number of trips made _is_ likely to change in response to transportation level-of-service changes. A measure such as an increase or decrease in gasoline price could affect the total number of discretionary trips made, but a traditional model system could not predict that.

- Trip distribution models often use distance or travel time by auto as the only measure of the level of transportation service--cost is omitted, as are transit service variables. The models thus cannot predict the effects of such policies as parking price increases or transit travel time reductions might have on destination choice.

- Mode split models traditionally have included only auto and transit. Such models cannot differentiate shared-ride (carpools, vanpools) from drive-alone, although such a differentiation is increasingly a factor in transportation operations planning.

Other computerized sketch planning models are available to deal with aspects of transit or paratransit forecasting. Paratransit modes, which generally are excluded from mode split models because of the difficulty in characterizing their level-of-service variables, may be studied with specially designed analysis tools. SAIM (73) is designed to identify potential areas for successful paratransit operation, while FORCAST (12) is designed to equilibrate supply and demand conditions for the analysis of dial-a-ride systems. Special techniques also exist for analyzing more conventional transit systems alternatives. One such method, the Transit Sketch Planning Procedure (11), is described later in this section.

In addition to these limitations which apply in general to most aggregate model systems, certain characteristics of individual sketch planning procedures also may limit their applicability. For example, several procedures treat transit in a very general fashion or in some cases ignore it completely In TRIMS (50), for example, transit trips are considered for only one trip purpose (usually work) in any given run. Other models deal only with automobile use and may be used to estimate the amount of auto travel by highway system (SSDA), by highway system and time of day (RHEM), by highway system, time of day, and subarea (CAPM), or link-by-link independent estimates of auto volumes DTEM)[1].

Finally, in recent years a number of MPOs have integrated disaggregate travel demand models--usually for mode choice--into their transportation modelling process. In almost all cases, these models have coefficients which were estimated using observations of individual travel behavior, but they are being applied using aggregate zonal-based data.[2] They thus produce predictions of how "average" travellers would behave, and much of the variation in travel behavior is lost. In some recently-developed application procedures, individual households rather than traffic ones serve as the basic prediction unit. In this procedure, termed household sample enumeration, a representative sample of households is selected from the study area. The "study area" need not encompass an entire urban area; if major corridor or activity center-oriented measures are considered, it is possible to draw samples from these areas only. The disaggregate model then is applied to each household in the sample. Aggregate forecasts are obtained by expanding these travel predictions for individual households to represent areawide travel patterns.

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[1] These and other computerized methods are described 'n (70). CAPM is also described in Section 2.3.1.

[2] The biases inherent in such application procedures are discussed in (43).

One example of the application of this procedure to the analysis of transportation measures is the Short Range Generalized Policy Analysis method (SRGP,7). A description of SRGP is included as one of the three computerized sketch planning methods described in greater detail in the subsections which follow. The other methods are CAPM and the transit sketch planning procedure.

### 2.3.1 CAPM--Community Aggregate Planning Model[1]

CAPM is a highway sketch planning tool included in UTPS which is designed for the preliminary evaluation of large numbers of broadly defined alternatives. CAPM has the ability to directly address the following kinds of issues:

- Decisions as to the location, magnitude, and functional type of urban highway investments.
- Formulation of highway operating strategies useful in obtaining environmental and system performance objectives, such as pollution abatement or fuel conservation.
- Examination of the highway-related implications of future land development policies.

While CAPM does not treat transit systems explicitly, its utility is not limited to the evaluation of highway alternatives. CAPM can be used in conjunction with complementary transit sketch planning tools (e.g., transit corridor analysis) or can be used to assess the highway-related impacts of transit policies (e.g., the doubling of total patronage or the increase of transit's share of trips to the CBD by "X" percent).

An important feature of CAPM is that it presents side-by-side displays of the various performance measures for base year conditions and a future alternative set of conditions. This is accomplished by a two-step process. Initially, a program run analyzes base year conditions and creates an output data set. All subsequent runs with alternative data sets read the base year output and write the side-by-side comparisons. The impacts of any system improvements or policy change are, therefore, readily apparent.

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[1] Many references are available, including 21, 23, 42, 58, 59.

A second feature is ease of input preparation. The basic geographic analysis units are communities, ranging in size from 8 to 30 square miles. The only inputs necessary for the representation of an alternative are for each community:

- Exogenously estimated vehicle trip ends,
- Total lane-miles of arterials,
- Route numbers, average numbers of lanes and center-line miles of each freeway.

Other data necessary for the estimation of the large number of evaluation criteria output assume internal default values, although these may be easily changed if desired.

Another major feature of CAPM is that its outputs include a large number of performance measures which can be directly provided to decision-makers. These include measures of travel, system performance, environmental/social impacts, and system supply costs. These are output for the base and test alternative in juxtaposition and appear in three separate summary tables:

- for each individual community,
- for groups of communities having similar characteristics; e.g., all suburbs, and
- for the region as a whole.

The CAPM program consists of three interrelated components:

- Travel generator: Assuming the stability of an input base year regional work trip time, the generator uses a modified version of a direct assignment model to compute a system-sensitive estimate of the daily regional average trip distance (length). This, in turn, is used to estimate the average trip distance for each community by examining its geographical position relative to all other communities. These trip distances are passed to the trip distributor.

- Trip Distributor: The average distance from the generator module is used in an exponential trip distance distribution function to estimate total travel in each community as the sum of three components: (1) trips with both ends in the given community; (2) trips with one end in the community; and (3) trips with neither end in the community. A special assignment logic is used to assign each component to the proper highway system. This assignment logic assumes that freeway speeds are twice those on surface arterials. Under congested conditions this tends to overload freeways. A capacity restraint mechanism has thus been provided which adjusts the volumes on a given community freeway facility to ensure that its speed in the peak hour will be at least 15 percent higher than the competing surface arterial system in the same community. VMT in each community on freeways, surface arterials, and locals is passed to the performance module for use in criteria estimation.

- Performance Measurer: Using factors which are input by community type, the VMT's passed from the distributor are split directionally and temporally (peak, off-peak, other hours). By comparing volumes to capacities, speeds are calculated and in turn travel-related performance measures and impacts are computed for each direction/time period. These are summed (and weighted where appropriate) to yield daily totals. In addition, the direct impacts and costs of going from the base to the alternative test system are estimated. The output reports are produced by this section of the model. A list of the reports is as follows (all are optional):

    - Community Type Statistics
    - Performance Factors
    - Community Location Data
    - Base Community Attributes
    - Base Freeway Route Data
    - Base Freeway Route Intersections
    - Alternative Community Attributes
    - Alternative Freeway Route Data
    - Alternative Freeway Route Intersections
    - Metropolitan Area Specific Data
    - ADT on Freeway Segments
    - Community Travel Breakdown by System
    - Metropolitan Area Summary
    - Community Type Summary
    - Community Specific Reports.

As an option, the impacts and costs can be reported for autos and trucks separately, as well as totalled, in the last three reports.

Suggested Applications--As a tool for the analysis of air quality-oriented transportation measures, CAPM is significantly limited by its lack of explicit treatment of transit systems and of the mode choice aspect of travel behavior. These missing components limit its applicability to urban areas (generally small) with no existing or planned public transit service; and for cities with transit service, to transportation measures which are strictly highway-oriented and are not expected to impact transit usage in any significant way. CAPM is also limited to the analysis of alternatives which can be realistically represented by changes in the following highway system characteristics:

- by freeway facility: maximum speed, capacity, ramp spacing, number of lanes, and connectivity with other freeway facilities;
- averaged over entire communities (8 to 30 square miles): surface arterial maximum speed, capacity per lane, traffic signals per mile, and number of lane-miles; local street average speed.

The following types of air quality-oriented highway system measures are not amenable to analysis using CAPM:

- parking supply or pricing changes
- high-occupancy vehicle lanes and roadways
- very localized traffic flow improvements
- bridge or roadway toll policies
- carpool and vanpool incentives

CAPM can predict average trip distances and trip routing, but all other aspects of travel demand must be provided as input data, either in the form of auto trip ends by community, or as person trips, transit trips and auto occupancy by community.

To summarize, given CAPM's limitations discussed above, it can be considered for use in the following ways as part of the analysis of air quality-oriented transportation measures:

- to analyze policies such as auto-restricted zones, traffic flow improvements, and staggered work hours in cities with no public transit service;
- to develop base data on highway system usage and the resulting cost, energy consumption, air quality, safety, an travel speed impacts; and
- after the prediction of the demand impacts of any transportation measure using other techniques, to develop estimates of revisions in highway system usage and the resulting impacts.

### 2.3.2 SRGP--Short Range Generalized Policy Analysis[1]

Short Range Generalized Policy Analysis (SRGP) is a computerized sketch planning methodology which employs a set of interrelated disaggre- gate travel demand models to predict the near-term impacts of transporta- tion measures--e.g., changes in household auto ownership level, work trip mode choice, and non-work trip frequency, destination, and mode choice. SRGP was designed to combine theoretical innovations with a number of soft- ware features to produce a user-oriented, practical planning tool respon- sive to the transportation, air quality and energy conservation analysis needs of metropolitan planning organizations. Case study applications of SRGP were carried out in cooperation with the Denver, Dallas/Fort Worth, and San Francisco MPO's. Since then, SRGP has been used in a number of applications in each of these urban areas, and has produced analysis results quickly and efficiently. Examples of these applications appear in Case Study IV in Volume II.

Calculation Procedure--SRGP links together eight disaggregate travel demand models to predict auto ownership, work trip mode choice, and non- work travel, all conditional on fixed household and employment locations. This conditionality implies that while SRGP captures the near-term impact transportation measures would have, impacts which might occur over a longer term, such as the number and distribution of work trips and location and land use patterns, are assumed to remain the same during the analysis period.[1] SRGP shares this assumption with most traditional model systems in which land-use patterns are generated exogenously and work trip generation is not predicted as a function of transport service levels.

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[1] Complete user documentation for SRGP may be found in (8). In-depth discussion of SRGP's capabilities is contained in (6) and (7).

The models included in SRGP are:

- an auto ownership model for households with one or more workers;
- an auto ownership model for households with no workers;
- a work mode choice model;
- a carpool size model for work trips;
- a shopping trip generation model;
- a social-recreational trip generation model;
- a simultaneous destination and mode choice model for shopping trips; and
- a simultaneous destination and mode choice model for social-recreational trips.

With three exceptions, each of these models is of the multinomial logit form. The two non-work trip generation models are specified as linear regression models.

As illustrated in Figure 2.3, these models are linked together in two ways:

- Shorter-term or lower-level choices are conditional on the outcome of longer-term or higher-level choices as represented by the solid lines in Figure 2.3. For example, decisions concerning work trip mode choice are conditional on predetermined household auto ownership levels. This type of linkage corresponds to that typically found in traditional aggregate model systems.

---

[1] Note, however, that it is possible to predict the near-term impacts of a transportation measure implemented during some future analysis year. In Denver, for example, 1985 was used as the base year; household and employment locations were assumed to be unchanged by the policies tested (9).

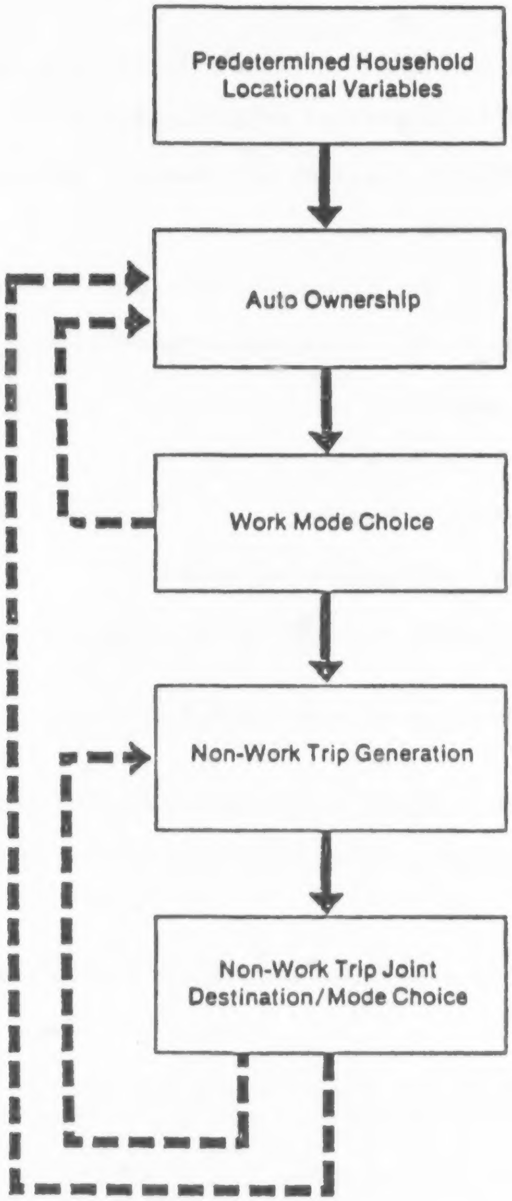
Predetermined Household Locational Variables
Auto Ownership
Work Mode Choice
Non-Work Trip Generation
Non-Work Trip Joint Destination/Mode Choice

FIGURE 2.3

Interrelationships of Travel Demand Models

- Higher-level decisions are based on expectations of lower-level choices. For example, the choice of household auto ownership level is influenced, at least in part, by the characteristics of alternative means of travel for both work and non-work travel. Similarly, non-work trip generation is sensitive to transportation levels of service for each potential destination. These linkages from lower level choices to higher level choices are illustrated by the dotted arrows in Figure 2.3 and typically are not found in aggregate model systems.

Software Capabilities--SRGP was designed and developed within the UTPS framework and was written as a user-coded subroutine of UMODEL (71). This UMODEL setting imposes a user-oriented structure on SRGP and provides standardized input and output facilities for communications with other UTPS programs. The input data are specified in such a way that they can be produced easily from a typical household interview survey and normal network analysis techniques.

SRGP has been designed to allow the user to tailor any model run to the specific conditions being analyzed. SRGP has an "update" feature which permits the user to modify any input data on a zonal or interchange basis. Multiplicative and/or additive changes to the data are specified by making simple changes to the job control parameters at the time the run is submitted. Thus, rather than developing new input data to represent a particular transportation measure, the base data are modified within the program to reflect any changes in level of service for those areas or trip interchanges affected.

The user also can specify the demand models to be used for a particular run. This feature results in significant savings when analyzing measures which have direct impacts only on home-to-work travel and for which any secondary impacts on non-work travel can be ignored. Predicting work trip mode choice, which involves at most three (or possibly four) modal alternatives per observation, is considerably less expensive than estimating choice probabilities and related impacts for all mode/destination combinations available to a household for non-work trips, which typically involves many more alternatives.[1]

It is also possible to alter SRGP model coefficients. However, this option has been used primarily for adjusting model coefficients when initially setting up SRGP in an urban area to ensure that SRGP predictions match base year observed data.

Adaptation to a Specific Urban Area--The work required for an MPO to integrate SRGP within its planning process can be organized into three tasks:

- Develop base year data files;
- Adjust model coefficients;
- Update base year data as required;

Three types of base year data are required by SRGP: a sample of households, transportation levels of service (both peak and off-peak), and land-use characteristics on a zonal basis. The ideal source of required household data is a recent home interview survey or an older survey updated to reflect current population characteristics. These surveys typically provide information on a much greater number of households than necessary and are generally quite complete in terms of fulfilling the data needs of the model system.

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[1] In the Denver study, the computer cost for the analysis of work trip mode choice only for a sample of 2,027 households was approximately $4.00 per run. For the analysis of both work and non-work travel for 506 households using separate samples of 50 destinations each for shopping travel and social/recreational travel, though, the run cost was $37. In order to reduce run costs, an optional destination sampling procedure has been incorporated within SRGP. Using this option, it is possible to select a sample of destinations for which choice probabilities will be calculated. Experience has shown that sampling 50 out of 276 possible destinations results in no significant decrease in accuracy.

If such a survey does not exist, there are two alternatives:

- Conduct a new, small sample survey;
- Synthesize artificial household-level data from Census data.

The medium used for conducting a new, small sample survey need not be restricted to the home interview. In the Dallas/Fort Worth area, for example, telephone interviews with mail-out/mail-back follow-ups were used to develop the required household sample.

Most urban areas have transit and highway networks coded in standardized formats from which the required transportation level-of-service data can be obtained. Similarly, land-use studies have been conducted in most urban areas and can provide the required population, employment, and other land use-related data.

Experience in adapting SRGP to specific urban areas has shown that this task, development of base year data, usually requires the greatest amount of effort. Depending on the availability and status of required data, this task typically requires six to ten person-weeks.

Some of the model coefficients incorporated within SRGP generally have to be adjusted in order to replicate base case conditions. There is a theoretical basis, supported by empirical evidence, for transferring the estimated relationships among travel time, cost, income, etc.; however, no such basis exists for transferring alternative-specific constant terms, which essentially capture the effects of all other factors influencing the choice process not explicitly modelled (54). Thus the strategy for transferring models among urban areas is to accept the estimated coefficients for time, cost, income, etc., and adjust only the constant terms. This is done by applying the model in the same way it is applied in forecasting. The predicted results are compared with those observed, and the constant terms are adjusted to compensate for any differences. This task is relatively straightforward, typically requiring one person-week to accomplish. This process is described in Section 5.5.5.

For many applications, some data updating may be necessary if the available data is not representative of the time period for which the analysis is to be performed. For example, in some cases it may be necessary to utilize an out-of-date interview survey as the source of household data; other applications may require that a future year be used as a base for the analysis. In either case, it is desirable to update from one point in time to reflect actual or projected changes in population and employment characteristics at a later point in time. Similarly, level-of-service and zonal characteristics may require updating. The procedures most appropriate for updating these data vary, depending on the type of data being updated (i.e., zonal, level of service, or household) and the level of detail desired.[1]

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[1] Several such procedures are discussed in (7).

Suggested Applications--SRGP can be used as a sketch planning tool by MPO's in the analysis of a wide range of transportation policies. It has been used in varied applications in several urban areas. Unlike many traditional travel demand models, SRGP explicitly considers carpooling as a distinct alternative in the choice of mode for work travel. Vanpooling, too, can be included as a separate mode.

In terms of applicability to specific transportation measures, two steps are required:

- the measure must be translated into changes in variables included in the model system;
- those individuals actually affected by the measure must be identified within the model system.

The majority of transportation measures being considered can be expressed in terms of changes in auto or transit travel time or costs and therefore are easily represented by SRGP. In the case of carpool matching and promotion, an "incentives" variable is included in SRGP, which is based on earlier modelling work.[1]

The second requirement is that the group affected by a measure be identified. For those transportation measures defined on a geographic basis (i.e., areawide ridesharing programs, CBD parking restrictions, etc.), this is straightforward, although for very small areas, care must be taken to ensure that the sample size is adequate. For those transportation measures that are generally restricted to major employers (such as carpool and vanpool programs), SRGP is capable of distinguishing impacts by employer size. Facility or route-specific transportation measures (i.e., HOV lane, tolls, etc.) are more difficult to analyze. Although it is possible to judgmentally assign trip interchanges to a specific facility, unless the facility is isolated (such as a bridge crossing), such a procedure may not be realistic. Further, unless the facility is heavily used, the number of trips in the household sample that would use the facility may be too small to allow any meaningful analysis. A more appropriate application of SRGP to measures such as these would be to analyze their potential on a system-wide basis (i.e., HOV lanes on all major facilities serving the CBD, areawide program of signal timing improvements, etc.).

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[1] See Case Study IV, Volume II, and reference (6) for more detail on the carpooling incentives variable.

SRGP has trip-based emissions and fuel consumption submodels which interface directly with the individual travel demand models and are sensitive to changes in average speed, trip length, cold-start conditions, and vehicle weight. Thus, SRGP can analyze measures which improve traffic flow leading to increased VMT, but which result in a net decrease in emissions by improving operating conditions.

### 2.3.3 Transit Sketch Planning Procedure (11)

This technique was developed primarily as a sketch planning model for transit systems analysis and design; the highway system is treated at a very general level. The procedure links together a series of computer and manual calculations into an analysis methodology similar to that used in detailed urban transportation planning models, but introduces a number of features which significantly reduce time and cost requirements while maintaining a relatively high level of accuracy.

Given a set of analysis year trip tables, the procedure predicts mode shares for a representative sample of origin and destination (O/D) pairs, and then expands these to all O/D pairs to obtain transit and auto flows for the entire area. These transit flows are then assigned to a simplified transit network. Manual worksheets can be used in the steps for which less detail is needed or which involve calculations for the limited number of sampled O/D pairs; a computer is used in those steps which involve extensive calculations for all O/D paris. This worksheet/computer combination minimizes much of the time and expense associated with an "all computer" approach, while eliminating much of the tedium that can be associated with sketch planning procedures.

This procedure has been applied in studies of a wide range of transit alternatives in several urban areas. In a transit study for the City of Regina, Saskatchewan, Canada, for example, about 30 transit system designs ranging from fixed-route buses to detailed personal rapid transit networks were examined in less than five person-weeks of analyst's time (53). The procedure also has been used to study the feasibility of automated guideway transit systems in Dallas, Chicago and Atlanta and has been applied in Mexico City in an evaluation of several regional transit alternatives. It is suited for Phase I of UMTA's transit alternatives analysis process.

Calculation Procedure--Figure 2.4 shows the sequence of steps used in applying the model system. Initially, a zonal system is developed by combining existing traffic zones to form a maximum of 100 analysis zones. Then, a series of transit alternatives are formulated. The characteristics of each alternative are specified in system description log sheets, which include information such as headways, fares, station spacing, vehicle size, etc. (An example of such a log sheet is presented in Case Study V in Volume II.) In addition, a simple transit network, representing only network structure and link speeds, is coded, using a highway (non-line-oriented) network building program (UTPS progam HR).

The next step is selection of zone pairs which are representative of the types of transit service available in the urban area. Typically, the zone pair sample size ranges from 6 to 30. Because detailed demand analysis is performed only for these representative zone pairs, the sampling concept is one of the major efficiencies of this procedure. Each zone pair is divided into six "market segments" (or groups) based on the group's mode of access to transit (walk, auto, feeder) at both origin and destination (e.g., walk/walk, walk/feeder, feeder/walk, etc.). Transit service levels then are developed manually for each market segment, using the transit network (or a system map) and the system description log sheets. Similarly, auto service levels are developed manually. In this case, though, one service level is used for all market segments for a particular zone pair.

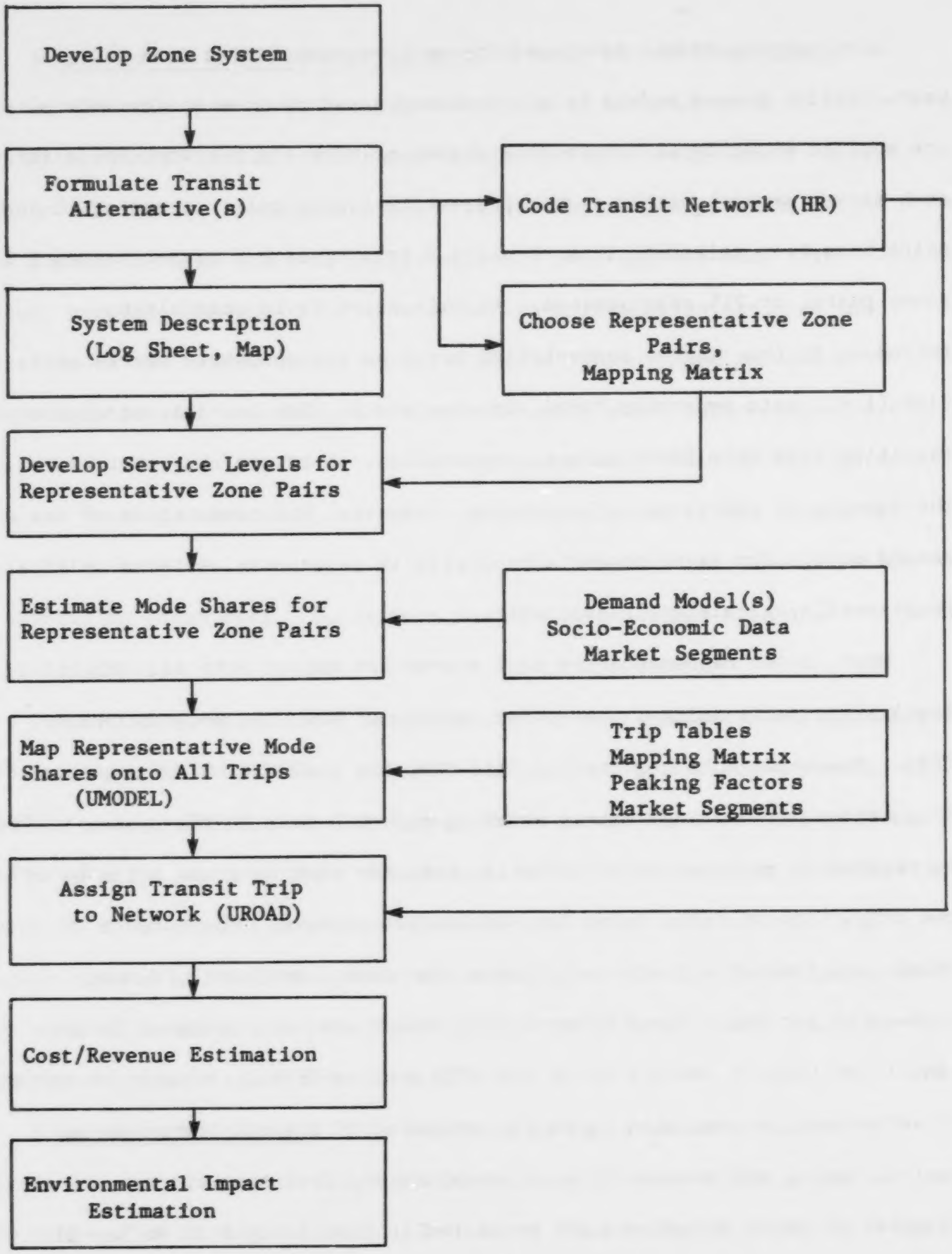
Develop Zone System
Formulate Transit Alternative(s)
Code Transit Network (HR)
System Description (Log Sheet, Map)
Choose Representative Zone Pairs, Mapping Matrix
Develop Service Levels for Representative Zone Pairs
Estimate Mode Shares for Representative Zone Pairs
Demand Model(s) Socio-Economic Data Market Segments
Map Representative Mode Shares onto All Trips (UMODEL)
Trip Tables Mapping Matrix Peaking Factors Market Segments
Assign Transit Trip to Network (UROAD)
Cost/Revenue Estimation
Environmental Impact Estimation

FIGURE 2.4

Major Steps in Sketch Planning Procedure

Source: (11)

With service levels developed for each representative zone pair, user-supplied demand models (e.g., work and non-work mode choice models) are applied manually to obtain mode shares of work and non-work trips for each market segment within each representative zone pair. Assuming 18 zone pairs have been selected, this requires 2 trip types X 6 market shares X 18 zones pairs, or 216 calculations. At this point it is possible to introduce further market segmentation based on socioeconomic characteristics (i.e., auto ownership level, income, etc.). The increase in accuracy resulting from this finer market segmentation, of course, is obtained at the expense of additional calculations. However, the computation of the demand models for these segments typically is quite easy, especially if a programmable calculator is available.

Next, these representative mode shares are mapped into all origin/destination pairs using a user-coded version of the UTPS program UMODEL (72). The input data required in this step are peak and off-peak person-trip tables, a "mapping" matrix relating each O/D pair in the system to its corresponding representative O/D pair, and, for each zone, an estimate of the proportion of total trips for each market segment. The outputs of UMODEL are transit and auto trip tables for peak (work) and off-peak (non-work) periods. These transit trip tables then are assigned to the simplified transit network using the UTPS program UROAD. Finally, a series of worksheets is completed to obtain estimates of transit operating and capital costs, and changes in auto emissions and fuel consumption. Examples of these worksheets are presented in Case Study V in Volume II.

Adaptation to a Specific Urban Area--Because of the flexibility inherent in this procedure, its implementation in an urban area is straightforward. Initial data requirements are relatively small: a 24-hour trip table, "peaking factors" (i.e., the percent of total trips made during the peak hour) to obtain separate peak and off-peak trip tables, and depending on the degree of market segmentation used and the variables in the travel demand models selected, certain socioeconomic characteristics for each analysis zone. The only other data required are those which are specific to each transit alternative. Many of the latter data are developed manually, and their accuracy depends on the analyst's familiarity with the urban area as well as the judgment and care exercised in developing these data. Guidelines for developing these data are available (11).

Two of the three computer programs used in this procedure are standard UTPS programs (HR and UROAD). The third program is a user-coded version of the UTPS program UMODEL. This program, which serves as the demand application program, accepts as input person-trip table data, and from it (and a number of other inputs) generates analysis year modal trip tables. All program options and control parameters are entered at run time by means of user control parameters; no modifications to the program itself would be required for use in other urban areas.

Suggested Applications--This procedure is applicable to transit improvement measures, including both capital improvement policies and a wide range of operating policies. Case Study V in Volume II shows an example of the use of the procedure to study a mixture of demand-responsive, express, and standard bus transit services.

Because auto travel has been treated only at a very general level of detail, vehicular emissions calculations are based on VMT only. If zone-to-zone auto distances and travel times were available, though, a more sophisticated emissions analysis procedure could be used with this sketch planning procedure. Using standards UTPS software, the auto person-trip table, already available with this procedure, could be merged with auto time and cost matrices to produce VMT summaries by trip length and speed class. These summaries then could be used in conjunction with the manual emissions worksheet described in Section 4.1.

# CHAPTER 3. TECHNIQUES FOR ANALYZING FACILITY OPERATIONS

Transportation facility operating characteristics are an important factor in transportation-air quality planning. Characteristics such as highway capacity and operating conditions and transit system capacity, frequency of service, and route coverage are critical determinants of traveller response to transportation measures. Facility operations potentially are affected, either directly or indirectly, by all transportation-air quality measures. Physical and operating characteristics may be directly altered by certain measures: by adding a highway lane or a turning channel; by adding new bus routes. Highway flows and transit level of service are also influenced indirectly by nearly all transportation measures, through changes in the demand for auto or transit travel. For example, higher auto costs may reduce the number of cars on the highways and thereby improve travel times, but increase the load on certain transit routes.

Because of the importance of highway operations analysis in transportation-air quality planning, this chapter focuses primarily on techniques for highway operations analysis. However, some techniques for analyzing bus system operations also are discussed.

Operations analysis needs vary significantly with the stage of planning. In the early stages of planning, there is a need for order of magnitude estimates of the relative implications of a large number of proposals to see which offer the greatest promise or have the highest probability of negative side effects. "Back-of-the-envelope" calculator or worksheet based methods, and transfer of relevant experience from other areas, would be appropriate at this level of analysis. In the later stages of planning, however, very detailed analysis methods are needed to determine the best design characteristics of facility and operations measures. These contrasting analytical requirements are exemplified by ramp metering, which can be screened for applicability by drawing on evidence from other areas with implementation experience, but must be planned with tools which can select the optimal set of metering rates given exact highway characteristics and traffic volumes.

At each level of analysis, the concern is with certain measures of transportation system performance, including times and costs to travellers, and assorted impacts of traffic, such as pollutant emissions, noise, and fuel consumption. All of these characteristics can be determined from two basic factors--traffic volume and speed. For highway operations, varying the level of analysis consists primarily of obtaining volume and speed estimates at different levels of detail, as in average speed over an entire freeway corridor, versus average speed over each freeway link, versus continuous speed profiles along the freeway.

Analysis methods for highway operations are restricted by computational difficulties. Traffic engineering is one of the most intensively studied aspects of transportation. There is a growing body of evidence from previous experience with such measures which can be used to screen an initial list of strategies. Further, traffic engineers have developed a good understanding of traffic flow theory--i.e., the relationships among traffic volumes, speeds, and vehicle density on facilities--and of queuing and delay characteristics at intersections and when volumes approach capacities. Equations which embody this understanding can be used to study the traffic characteristics of individual highway and street links and intersections. But realistic application of traffic flow principles over a larger segment of the highway system requires a level of analytical complexity which is handled most appropriately by a computer. Computer models have been developed for many applications, including preferential freeway lanes, preferential treatment on local streets, ramp metering, and network signal optimization, as well as more mundane roadway improvements and changes in traffic volume which result from other transportation measures. Because of their expense and level of effort, many of these computer models are impractical for transportation-air quality planning, but others can and should be employed when the resources are available.

## 3.1 Manual Techniques

In view of the data requirements of computerized highway models, there is a strong incentive to fall back on simpler, more approximate, non-computerized methods. Many such techniques are available. They fall roughly into three categories:

- empirical and theoretical traffic flow relationships;
- graphical techniques; and
- transfer of experience, locally and from other areas.

The sections which follow discuss each of these categories in turn.

### 3.1.1 Traffic Flow Relationships

Flow/density/travel time and queuing relationships initially were developed to describe the behavior of traffic on individual components of the highway system. Many of these equations depict isolated highway or street traffic phenomena, such as delay at signalized intersections and volume-travel time relationships on uninterrupted links.

Intersection delay/signal timing methods are perhaps the most familiar. In 1966, Webster and Cobbe published an intersection analysis approach based on queuing theory and on observations of traffic in the United Kingdom (76). They provided equations for determining:

- saturation flow (i.e, capacity) of each approach to an intersection, given roadway geometry;
- optimal cycle length, given traffic and pedestrian volumes and pedestrian crossing times;
- optimal green time; and
- average delay (or time spent at the intersection) for each approach.

While other intersection analysis methods are available, Webster's has received the widest field application. His equations are ideally suited for programmable calculator and worksheet approaches. Program libraries which include the basic Webster equations are available (18,48). These can be extremely useful for transportation-air quality planning in a limited but important way, by helping to identify intersections which may be mis-timed and by providing a first-cut estimate of the potential time savings from a better signal timing scheme. Unfortunately, Webster's approach is inappropriate for actual signal re-timing in an urban network, because it assumes an isolated intersection and random arrivals of vehicles from all directions. Courage has taken some initial steps in his work to account for non-random, platooned arrivals which characterize most urban arterial and network intersections (19). Additional refinements to translate intersection programs to provide useful arterial analysis tools are considered feasible, through the use of iterative (stepwise) calculations of intersection-by-intersection performance. Howevber, the time and cost of following such a procedure could rival the expense of setting up and running computer programs such as FREQ and TRANSYT.[1]

Isolated links in the highway system also have been treated extensively in the traffic engineering literature. There is both an empirical and a theoretical strain in this work, but the two viewpoints turn on the same fundamental concept: that speed (miles per hour), traffic density (vehicles per mile) and traffic volumes (vehicles per hour) are related in obvious ways.

Theoretical researchers have sought to infer these relationships directly from physical and probabilistic principles, while empiricists have collected data (particularly density/speed observations) and estimated parameters for various equations. Some data are presented in raw form, as tables, charts, or nomographs.[2]

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[1] The FREQ and TRANSYT programs are described in Section 3.3.1 (57).

[2] See the Highway Capacity Manual (36).

Both approaches have produced reasonably accurate tools for predicting travel times on uninterrupted stretches of roadway, such as long freeway links with constant physical characteristics and no ramps. Even freeway segments with on- and off-ramps are modelled adequately by these equations, at least for volumes well below capacity. However, there is a significant problem: the relationships do not hold as volumes approach capacity, yet congestion is the most important aspect of a traffic flow analysis. Special calculations are necessary to represent the consequences of queue spillback at "oversaturated" locations.

For non-congested conditions, there still may be some value in a straightforward volume/speed relationship. In particular, some researchers have developed approximate equations for entire arterial segments including links and intersections, both signalized and unsignalized. An example is the model for arterial travel time originally proposed by Davidson (22). This model, developed using elements of queuing theory, is an equation which relates traffic flow and average route travel time. The equation is:

$$t = t_o\left(1 + \frac{J\, q/c}{1 - q/c}\right)$$

where:

$t$ = travel time per unit distance

$t_o$ = minimum travel time per unit distance, e.g. at zero flow

$J$ = the Davidson parameter

$q$ = traffic flow

$c$ = road capacity

J is intended to represent physical/environmental factors, although attempts to classify roads by environment have not been successful. The $t_o$ parameter approximates what could be considered travel time at free flow speed, including some service delay at signals. Thus, $t_o$ could be measured in early morning conditions on a route, but substituting the travel time at free-flow speed is sufficient. The value of c can be computed easily, and J can be calculated through regression or some other ad hoc estimation method for an existing arterial data base, or adapted from evidence on prior values.

Jovanis has applied this model to Bay Area data with a great deal of success (40). Observed versus predicted travel times for a major arterial are shown in Table 3.1. This method could provide a useful approximation to the travel time effects of change in arterial flows for specific corridors, or even on classes of facilities in a metropolitan area.

It is difficult to conceive of extensive applications for non-computerized traffic flow relationships in transportation planning. At the sketch planning stage, measures are too broadly defined to permit an analysis of specific facilities, and in the design stage, most analysis needs are too complex for calculator or worksheet methods. There are occasional circumstances in which traffic flow relationships would suffice--for example, a unique facility, such as a toll bridge with metering, could be evaluated with simple queuing models--but most realistic analyses would be burdensome without the aid of a computer.

| SEGMENT OF ARTERIAL | ARTERIAL TRAVEL TIMES (SECONDS) | |
|---|---|---|
| | FIELD MEASUREMENTS | DAVIDSON EQUATION RESULTS |
| 1 | 111 | 110 |
| 2 | 132 | 129 |
| 3 | 145 | 155 |
| 4 | 82 | 76 |
| 5 | 7 | 25 |
| 6 | 100 | 98 |
| 7 | 24 | 24 |
| 8 | 28 | 33 |

TABLE 3.1

Comparison of Field Measurements with Davidson Equation Computations

(Location: San Pablo Avenue in Richmond, El Cerrito, Albany, and Berkeley, California)

Source: (39)

### 3.1.2 Graphical Techniques[1]

One of the few non-computer methods which have had widespread, legitimate application is a graphical technique for determining the best signal progression along an arterial. The analyst begins with a diagram of the arterial and its intersections represented in time and space, as in Figure 3.1. Cycle lengths and splits are determined previously, using Webster or a similar method (cycle length should be the same for all intersections, to permit a consistent progression), and are plotted horizontally, starting at the location of each intersection on the distance axis. Figure 3.1 shows the red phases beginning at the same time for all three intersections. A line representing the average speed on the arterial (speed=distance/time) reveals that vehicles would stop at every intersection under this scheme. For travel in one direction, the progression is improved by changing the cycle start times to maximize the bandwidth--the time window drivers would have for getting through all three intersections without stopping--for a speed of 25 miles per hour, as in Figure 3.2.

If the arterial has approximately equal flows in both directions, a two-way progression is necessary. In Figure 3.2, the start times appear to be correct for two-way flow, but generally they would require further adjustment to provide an acceptable bandwidth in each direction.

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[1] For an in-depth discussion of the use of graphical techniques, see (38).

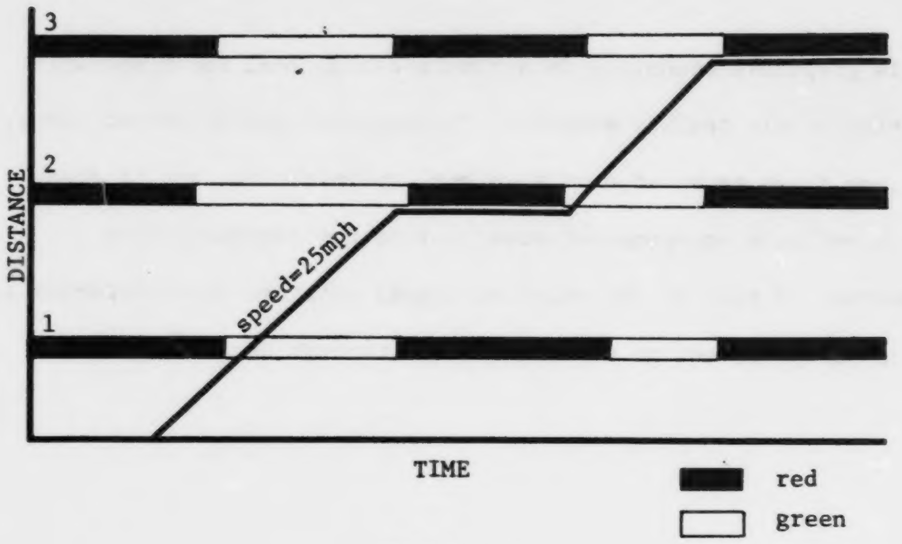

3
2
1
DISTANCE
TIME
speed=25mph
red
green

FIGURE 3.1

Basic Intersection Diagram

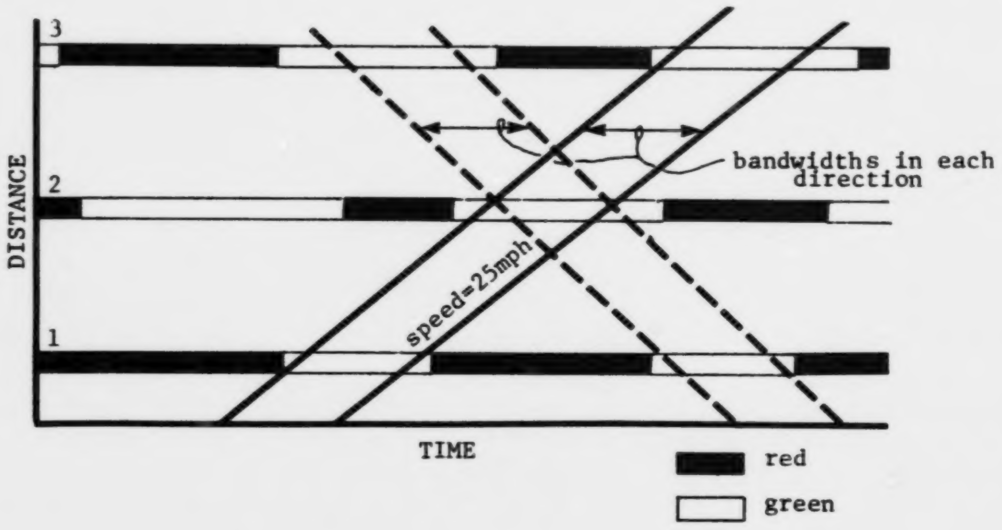

3
2
1
DISTANCE
TIME
speed=25mph
bandwidths in each direction
red
green

FIGURE 3.2

Traffic Signal Progression

This graphical technique is a simple design tool for a specific transportation-air quality measure. It does not compute travel times, impacts, or flows as an adjunct to signal optimization, but it does provide a reliable non-computer-based method for designing flow improvements. A plot of the existing signal settings on an arterial also can indicate the potential for improvement through optimization.

### 3.1.3 Manual Areawide Traffic Engineering Analysis Method (74)

The majority of methods for facility analysis were designed for site-specific or project level studies. Much less work has been done on tools for estimating the cumulative, areawide impacts of ubiquitous implementation of a site-specific measure, or for examining the interactions of travel demand with facility capacity and operations. Wagner has developed a simple approach for addressing both of these issues. The analysis approach is as follows:

- Given: An urban area highway system which serves an existing quantity of travel demand (VMT) at an existing level of travel quality (average travel time per vehicle mile), and
- A plan for implementing one or more major traffic engineering actions on different types of highways in the total system for the principal purpose of improving the quality of highway travel,
- Find: The resultant impact of the action(s) on total areawide highway travel demand (VMT), average travel time, and various impact measures.

The analysis is carried out in a sequence of steps, performed separately for work and non-work travel (corresponding approximately to peak period travel and off-peak period travel). The steps are:

- segmenting the highway network into functional classes having significantly different travel time characteristics;
- determining the fraction of base year VMT on each functional class;
- specifying an approximate travel time/volume relation for each functional class, expressed as the elasticity of travel time to changes in VMT;
- identifying the measures which affect each class, and estimating the potential improvements by drawing on transferred experience and model results;

- collapsing the class-by-class data into single impact estimates for each measure.

The method, which exploits the wealth of descriptive regional highway network data which is available to most MPO's, can be used as a first-cut tool for assessing the areawide impacts of traffic management and control strategies and combined packages of measures. The method is illustrated in Case Study VI of Volume II.

### 3.1.4 Transfer of Experience

Evidence from previously implemented highway measures and other analytical efforts can be invaluable in sketch-planning analyses. Most analytical tools, as discussed above, apply to site-specific, project level impacts and entail considerable effort and expense. In many circumstances, detailed analyses will be infeasible because of resource constraints, or because the measures are too vaguely defined. In these cases, experience on other similar projects may apply, or the "typical" impacts of measures may be inferred from a sample of existing projects.

There are many sources of data about the effects of highway measures. Published compilations document a wide variety of before and after studies, but focus principally on demand effects and fail to discuss the underlying assumptions in sufficient detail. Primary documents from actual projects around the country are the major source of information: they outline the travel time improvements and reductions in congestion which have resulted from specific highway operational improvements. Researchers are beginning to consolidate these data into concise, accessible formats. For example, Wagner gathered data on signalization improvements and freeway control, among other things. Typical data from that effort are shown in Tables 3.2 and 3.3 (74).

In transferring these results to another project, one would not simply apply the sample average impact blindly. There is wide variation in the data, indicating different underlying circumstances for each project. In Table 3.2, two of the cities, Toronto and San Jose, already had computerized control systems and relatively thorough programs

## TABLE 3.2

## Traffic Signal Timing Optimization Impacts

| Location | Number of Intersections | Study Method | Time of Day | Average Speed, Mph | | |
|---|---|---|---|---|---|---|
| | | | | Before | After | Percent Change |
| Toronto Central Area | 68 | Field Measurement | 7-9 | 15.8 | 16.5 | + 4.4 |
| | | | 10-12 | 17.1 | 17.5 | + 2.3 |
| | | | 1-3 | 15.5 | 16.3 | + 5.2 |
| | | | 4-6 | 13.7 | 13.7 | 0 |
| Toronto Suburban Area | 51 | Field Measurement | 7-9 | 21.3 | 21.0 | - 1.4 |
| | | | 10-12 | 28.2 | 29.1 | + 3.2 |
| | | | 1-3 | 27.5 | 28.1 | + 2.2 |
| | | | 4-6 | 21.7 | 20.9 | - 3.7 |
| San Jose - CBD | 46 | TRANS Simulation | 4-6 | 15.4 | 15.7 | + 1.9 |
| Los Angeles - Inner City (Broadway - Figueroa) | 26 | TRANS Simulation | 3-4, 5:30-6 | 17.4 | 20.6 | +21.1 |
| | | | 4-5:30 | 15.4 | 18.9 | +22.7 |
| Los Angeles - Inner City (Pico Boulevard) | 6 | TRANS Simulation | 2:30-3:30 | 21.1 | 24.9 | +18.0 |
| | | | 4:30-5:30 | 20.2 | 21.5 | + 6.4 |
| Los Angeles - Inner City (Wilshire Boulevard) | 45 | TRANS Simulation | AM Peak | 13.1 | 14.4 | + 9.9 |
| Macon, Georgia CBD | 54 | SIGOP Simulation | 7:45-8:45 | 12.7 | 14.4 | +13.4 |
| | | | 4:45-5:45 | 11.7 | 13.7 | +17.1 |
| Inglewood, California Citywide | 60 | SIGOP Simulation | 7-10 | 22.9 | 30.9 | +35.0 |
| | | | 3-6 | 22.0 | 30.0 | +36.0 |
| Montgomery, Alabama CBD | 50 | TRANSYT Simulation | AM Peak | 16.31 | 20.24 | +24.1 |
| | | | Off Peak | 19.09 | 20.26 | + 6.1 |
| | | | PM Peak | 17.94 | 19.87 | +10.8 |
| Charlotte, NC CBD Fringe | 10 | TRANS Simulation | 5-6 | 7.68 | 8.66 | +25.8 |
| Washington, DC CBD | 40 | UTCS-1(NETSIM) | Off Peak | 11.97 | 13.22 | +10.4 |
| Average, All Locations: | | | | | | +11.8 |
| Average, Toronto & San Jose | | | | | | + 1.6 |
| Average, All Others: | | | | | | +18.4 |

Note: Toronto and San Jose were aggressively managed, computerized signal systems in the BEFORE case

Source: (74)

## TABLE 3.3

## Freeway Ramp Control System Impacts on Average Speed

| Location | Length, Miles | Time of Day | Before Ramp Control | After Ramp Control | Percent Difference vs. Before | After, Including Ramp Delays | Percent Difference vs. Before |
|---|---|---|---|---|---|---|---|
| Minneapolis I-35W | | | | | | | |
| Northbound | 16.6 | 7:15-8:15 | 33.8 | 45.5 | 34 | 43.0 | 27 |
| (Inbound) | 16.6 | 6:30-9:00 | 43.9 | 50.1 | 14 | 48.5 | 10 |
| Southbound | 12.7 | 4:30-5:30 | 33.7 | 40.1 | 19 | 38.6 | 15 |
| (Outbound) | 12.7 | 3:3--6:30 | 38.5 | 45.7 | 19 | 44.4 | 15 |
| Chicago, Eisenhouwer Expressway | | | | | | | |
| Eastbound | 9.4 | 2 hour AM Peak | 30.3 | 33.0 | 9 | | |
| (Inbound) | 9.4 | 4 Hour AM Peak | 37.7 | 39.7 | 5 | | |
| Los Angeles, Santa Monica Freeway | | | | | | | |
| Eastbound (Inbound) | 13.5 | 6:30-9:30 | 36.2 | 50.6 | 40 | 41.4 | 14 |
| Houston, Gulf Freeway | | | | | | | |
| Northbound (Inbound) | 6 | 7:00-8:00 | 20.4 | 32.6 | 60 | | |
| Los Angeles Harbor Freeway | | | | | | | |
| Southbound | 4 | 3:45-6:15 | 25.9 | 40.3 | 55 | 37.4 | 44 |
| (Outbound) | 4 | 3:45-6:15 | 25.9 | 40.3 | 55 | 37.4 | 44 |
| Detroit, Lodge Freeway | | | | | | | |
| Northbound (Outbound) | 6 | 2:30-6:30 | 27.3 | 36.4 | 33 | 32.6 | 19 |
| Averages All Data | | | 32.8 | 41.4 | 26 | | |
| Averages for Data Including Ramp Delays | | | 34.2 | | | 40.8 | 19 |

Source: (74).

of ongoing signal timing work. Their impacts thus represent a refinement of high quality timing plans, and the resulting percent improvements are markedly smaller than for the other cities. For judging the potential improvement from computerized signal optimization, the status of the existing system would be an important factor in determining which results were most applicable to the new situation.

Ideally, experience within a metropolitan area could be used to judge the potential of other, similar measures in that area. For example, the impacts of a preferential lane in one freeway corridor may indicate the likely effects for similar corridors in the region; signal optimization in one city may mirror the potential for improvement on equivalent facilities in nearby cities. Where there is no experience with similar measures, modelling results from planning studies in the area may suffice. Thus, if ramp metering had been studied for one or more corridors, the predicted impacts might be transferred to other corridors, taking into consideration the similarities and differences which might affect the analysis.

Model results also can be used to develop approximate relations between travel time and traffic levels for entire facilities. In a freeway corridor, for example, successive runs of FREQ (40) for different flow assumptions would measure the elasticity of travel time with respect to volume. These elasticities then could provide a "first cut" approximation of the effect on level of service caused by a change in travel demand in the corridor. By extension of this approach to other major freeway corridors in the region, and to principal arterials through applications of the TRANSYT (57) package, a more comprehensive set of elasticities could be developed. Alternatively, the elasticity relations from a handful of model applications might be applied region-wide, if initial results for different facilities were in close agreement.

Previous experience and model results remain difficult to apply at the most general level of policy articulation--regionwide strategies. Yet such broad initiatives are characteristic in the preliminary phases of planning. In assigning priorities for further study to various measures, it helps to know their likely relative impacts. For example, how much would a comprehensive signal optimization plan reduce the average trip time for all travellers? Data shown in Tables 3.2 and 3.3 cannot address this question directly, because the fraction of travel occurring on heavily signalized facilities is not known. In fact, this problem applies generally to analysis at the regional scale--it is difficult to translate highway-related impacts from specific projects to aggregate regional measures of effectiveness.

## 3.2 Calculator Methods

To date there are very few calculator methods available for facility operations analysis, since a level of complexity requiring computer approaches is reached quickly in many applications. The set of programs developed by Murphy (52) shows the potential of programmable calculators for these analyses. These programs emphasize traffic engineering methods for localized application, such as signal intersection delay computation, signal cycle length optimization, signal synchronization for maximum bandwidth, and traffic counting distribution selection.

Transit operations calculator methods are just beginning to be developed. A program for analyzing bus system operations is described in the following section; an example application is contained in Case Study III in Volume II.

### 3.2.1 Program BUS (48)

Program BUS simulates the operation of one or several buses over a specific route. It is used to predict running times, actual headways and passengers on board as consequences of traffic congestion and bunching, given scheduled headways and operating speeds. Various strategies such as exclusive bus lanes, intersection controls, bus schedules and speeds may be evaluated using the program.

Calculation Procedure--The logic of the program involves moving buses one-by-one along a route, simulating each vehicle's performance. The route is broken up into three types of segments: line segments, street intersections, and stations. Vehicles are moved through a succession of route segments specified by the user.

The time spent in each section depends on traffic volumes, passenger arrival rates, and the operating characteristics of the vehicles. Vehicle acceleration, operating speed, and prevailing speed limits are inputs to the model. Travel time is calculated employing basic kinematic relationships. The Webster relationship is used to calculate intersection delay as a function of vehicle volumes and signal operation (76), and a simple queuing model allows congestion to be modelled as well.

Passenger service delays at stations depend on the number of passengers boarding and alighting. The number of alighting passengers is assumed to be a fixed fraction of the volume on board the buses as they arrive at each station. Boarding passenger volumes depend on the passenger arrival rate at each station, the time elapsed since the previous bus departed from the station, and the number of passengers left unboarded by the previous bus. Passenger arrivals are random, with a Poisson distribution; the rates at which passengers arrive at stations must be determined by an independent estimate of bus passenger demand on the route and their distribution along the route.

As the bus is run through the route, segment by segment, the program keeps track of the number of passengers on board and the passage of time. A simulation record is provided to allow the analyst to simulate route operations by running a number of buses along the route in sequence.

Suggested Applications--The major use for program BUS in air quality planning is the translation of measures to improve bus service into changes in transportation level-of-service for use as input to travel demand models. Specifically, in-vehicle travel time and waiting time for passengers may be predicted. The program may also be used to determine the operating characteristics of proposed new bus routes given existing traffic volumes and intersection operations.

Equilibration or balancing of passenger demand and bus route supply--an important aspect of developing accurate impact estimates--may be accomplished by iteratively applying Program BUS and a travel demand forecasting procedure to determine actual operating characteristics and demand levels. Case Study III in Volume II demonstrates the use of program BUS in this way. Program BUS would have limited application to policy level or areawide analysis; it is better suited to the evaluation of specific routes and service options.

## 3.3 Computer Methods

Computerized highway models commonly are categorized by several attributes. "Microscopic" models represent the trajectories of individual vehicles moving through the highway system, while "macroscopic" models deal with the behavior of vehicle streams along different segments of the system, much as fluid flow is studied in mechanical engineering. "Stochastic" models assume that vehicle arrivals and trajectories will obey probabilistic principles, while "deterministic" models treat arrivals and trajectories as constants within each time period. These distinctions have relevance in planning, because they influence accuracy and expense; microscopic and stochastic models tend to be more complex and thus more expensive, while macroscopic and deterministic models are potentially less accurate.

In practice, no highway model is purely representative of any one category. Highly microscopic computer simulation models of traffic flow incorporating stochastic properties have been developed and used for analyzing the interactions between traffic performance, roadway geometrics, and traffic control features; while less microscopic, deterministic models of freeways and surface arterial networks have been applied to the full spectrum of transportation-air quality measures. Some of the most important of these models are discussed briefly below. More detailed descriptions of selected models are also provided in the sections which follow.

Micro-assignment is a deterministic tool for detailed analysis of urban road networks (20). It uses an incremental traffic assignment technique and a block-by-block origin-destination (O-D) table to simulate traffic operations in a study area of up to 1000 city blocks. It is most appropriate for evaluation of local road modifications, such as one-way streets, auto restricted zones, neighborhood traffic restraints, and the like. Micro-assignment employs a conventional approach with three main steps: network construction, path tracing, and traffic assignment. Each distinct traffic movement is represented by a separte link, and, unlike other network programs, any node can be an origin or destination for traffic. All types of intersection control are represented explicitly, including stop signs, yield signs, signals, and freeway ramps. Different origin-destination tables are provided by time period, and the model performs a full network assignment for each table. The program outputs include link volumes and traffic times, from which other impacts can be computed. Variations of the model have been used in several U.S. metropolitan areas. These applications have resulted in modifications which improve the representation of factors important to traffic flow, such as transit vehicles, pedestrians, and weaving. Nevertheless, the effort and expense of implementing the program have been deterrents to more widespread application, and severely limit the potential of micro-assignment for planning. Areas which already use such a model or can justify it on grounds other than air quality, however, may find it to be a useful tool in transportation-air quality analysis, as well.

NETSIM, like its predecessor UTCS-1, is a microscopic, network-based simulation model for developing and evaluating complex traffic management strategies (45). The model can treat all major forms of urban traffic control, including stop or yield signs, simple fixed-time traffic signals operating either independently or as part of a coordinated system, vehicle actuated signals, and signal systems operating under dynamic real-time control. NETSIM views each vehicle in the network as a separate entity. Vehicle motion is determined from performance characteristics which are input by the user, in conjunction with a set of algorithms covering car-following, queuing-discharge, and lane-switching. The exact position of each vehicle is updated for extremely short time intervals. Output of the model includes a comprehensive set of traffic performance mesures for each individual link and for the network as a whole, as well as data on emissions and fuel consumption. Although NETSIM is relatively new, UTCS-1 has been extensively appied and gives reasonable results.

TRANSYT is a technique for optimizing signal offsets and splits in a local street and arterial system (56,57). Like its predecessors, the most recent version of the model, TRANSYT6, provides a macroscopic deterministic simulation of traffic flow. Vehicles are represented by platoons which change as they proceed through signals and disperse along the roadway links. The street network is represented as a series of nodes connected by uni-directional links, and traffic volumes are given in a node-to-node origin-destination table. Signal settings are chosen to minimize a linear function of travel time and number of vehicle stops in the system. TRANSYT6 can model preferential treatment schemes for arterials, such as exclusive lanes and priority signalization. In practice, the program has been useful both as a design and as an evaluation tool. Because it requires a relatively small level of coding effort, and relies on explicit and reasonable assumptions, TRANSYT6 has been and continues to be implemented extensively.

TRANSYT6C is a modification of the existing TRANSYT6 model to include environmental consequences and certain traveller responses (39). In this effort, procedures were developed to account for fuel consumption and vehicle emissions and to model path and mode shifts, and the performance index was expanded to include a broader range of variables in the signal optimization. The new model has been tested extensively for applications in California.

SIGOP II is a signal optimization program developed for FHWA and is a descendant of TRANSYT and SIGOP I, also a signal optimization program (66). Like TRANSYT, it utilizes a macroscopic model to select signal timings which minimize a function of travel times and stops. Unlike TRANSYT, it employs a dynamic programming technique in which traffic streams are represented as "states" with specific properties. These states are transformed at intersections according to the decision variables of the program (i.e., the signalization parameters). SIGOP II has several attractive features for transportation-air quality planning. It can calculate the capacity of each intersection approach, which reduces the level of effort in data preparation, and it incorporates error messages and diagnostic tests for the user operating the program. However, SIGOP has not been applied as widely as TRANSYT, and the latest, most appropriate version is still undergoing field tests by FHWA.

FREQ6PE was developed for analyzing freeway design improvements and entry control strategies (40). It consists of two major parts. The first, SIMFRE, is a deterministic macroscopic simulation model which predicts traffic performance as a function of freeway design and ramp-to-ramp freeway volumes. SIMFRE generates traffic performance data in terms of miles of travel, travel time, fuel consumption, vehicle exhaust emissions, and vehicle noise emissions. The second, PREFO, is a linear programming optimization that is used to determine an entry control plan for a given freeway origin-destination pattern. The linear program allows a mixture of normal and priority entry control as well as special ramp treatments such as buses only.

These two routines are extremely useful in assessing the short-term impacts of strategies such as ramp metering. In a broader sense, the simulation model alone could be used to assess virtually any freeay configuration under analysis. In either case, the data requirements and run expenses are relatively modest.[1]

To represent the longer-term effects of ramp metering, FREQ6PE incorporates an ad hoc route and mode shift procedure. Elasticities are used to determine the effects of changes in travel time on mode choice, and minimum path assumptions are invoked to determine the extent of diversion to downstream ramps and parallel arterials. The data requirements and run costs in this case are somewhat higher, and the program results are more difficult to validate.

---

[1] Run costs range from $5 to $50 depending on how many of the program features are used.

FREQ6PL, an alternative version, incorporating the basic simulation program, was developed for analyzing freeway priority lanes (16). In an application for the Santa Monica Freeway, it came remarkably close to replicating the actual short- and medium-term impacts of the ill-fated "diamond" lane. (The project was terminated before its long-term impacts could be determined.)

From these few brief descriptions, it should be apparent that none of the computer-based techniques is truly a "sketch planning" tool. Nevertheless, some are more appropriate to the planning and design of transportation-air quality measures than others. Highly microscopic approaches like NETSIM yield powerful general purpose models with a wide range of applications to such pervasive measures as advanced traffic signal control strategies, bus lanes and bus priority signals, right-turn-on-red, etc. In addition, they are capable of detailed energy and emissions estimates based on individual vehicle trajectories, which permits estimation of a variable emissions profile along a line source. However, data preparation and computational requirements are unreasonably high for most planning applications, even for relatively small networks or linear arterials.

Less microscopic, deterministic computer models show a good deal more promise for small-scale planning applications. Two of these--the TRANSYT and FREQ series of programs--are particularly attractive in terms of the strategies which can be modelled, the quality of support documentation, and the relative ease of application. While they are not sketch planning tools in the strictest sense, TRANSYT and FREQ do have significant potential because of their reduced running costs and wide distribution to user groups. Once the investment in set-up and initial coding of selected freeways or portions of the arterial network has been made, many alternatives can be tested quickly and economically. Since both models are design (FREQ for designing freeway control strategies and TRANSYT for optimizing signal timing plans) as well as evaluation tools, the initial investment can double as a planning and as an implementation measure. It would not make sense to apply these tools comprehensively throughout the network, but they could be used for critical proglem corridors and subareas, or for a relatively small set of representative locations--which, in turn, could be extrapolated to assess areawide implications of traffic management and control actions.

Other deterministic models--notably micro-assignment--have been suggested for small-scale applications, especially for evaluating neighborhood traffic management actions. In some cases, the models, such as SIGOP, differ little from TRANSYT and FREQ and have been used much less extensively. In other cases, such as micro-assignment, the data and computational requirements are out of line with small-scale planning, and efforts to create more tractable versions are several years from fruition. In the remainder of this section, more detailed descriptions of TRANSYT and FREQ are presented as the best available computer methods of highway operations analysis for transportation-air quality planning. However, the reader should be aware that other existing models may be appropriate for specific purposes, and that future developments may broaden considerably the range of computer applcations for short-range analysis.

### 3.3.1 TRANSYT

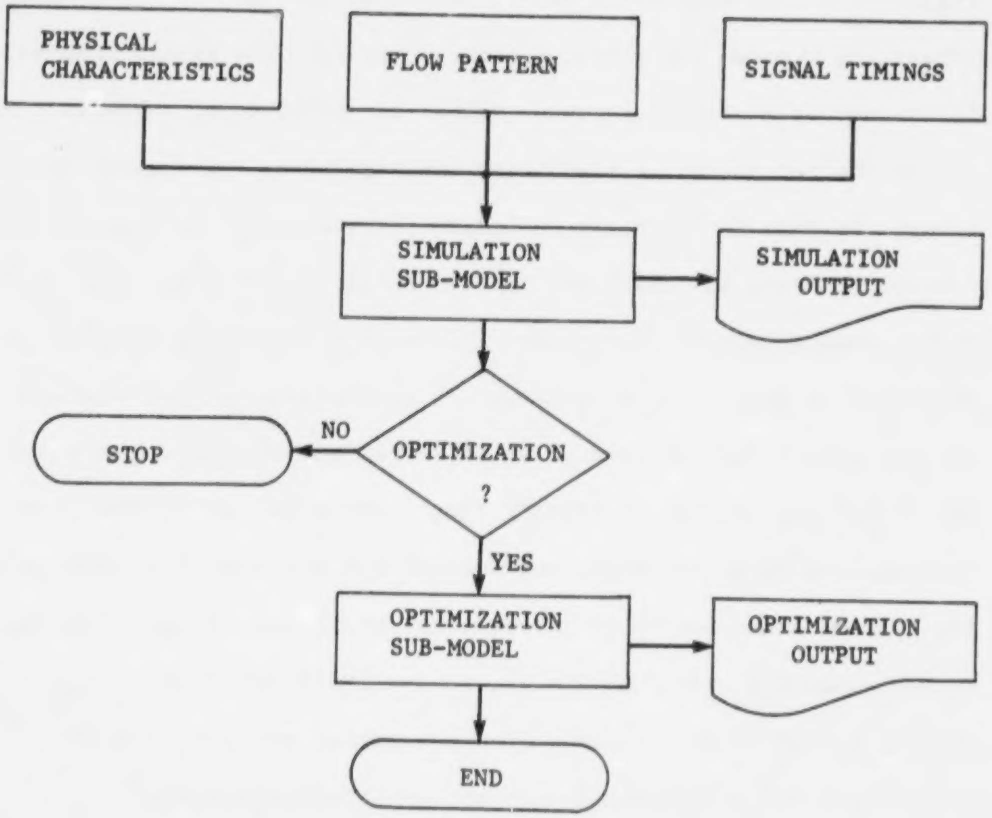
TRANSYT is a model which simulates traffic behavior in a network of urban arterials and optimizes the settings (offsets, cycle lengths and green time) of traffic signals. Six generations of the model have emerged from the transport and Road Research Laboratory (U.K.) since 1967, with successively more detailed representations of network and vehicle characteristics and an increasing range of traffic control strategies from which to choose (39, 56, 57). Recent versions have been adapted to deal explicitly with traffic management measures, to represent demand responses, and to allow flexibility in optimization of criteria (39).

TRANSYT requires a detailed specification of network geometry, link flows, and signalization criteria, including:

- a node number for each intersection;
- a separate link for each direction of flow feeding into an intersection. More than one link may be required for special lanes, such as for transit priority or for turning movements;
- saturation flows (in vehicles per hour) for each link, based on roadway widths and on simple principles of intersection capacity found in most traffic engineering texts;
- link travel times for uncongested flow, for both buses and cars;
- average flows in vehicles per hour for all links;
- amount of time required for pedestrians to safely cross at each intersection (considering width of intersection and number of pedestrians);
- existing signalization plan, with cycle lengths, green and amber times, and progression (if any);
- miscellaneous other parameters which specify run options, optimization criteria, fuel consumption characteristics, and output formats.

The TRANSYT program has two key sub-models: simulation and optimization. Their relation to overall program logic is shown in Figure 3.3. The simulation model focuses on the behavior of platoons travelling through the street system. Flow into the system from outside is assumed to arrive at constant rates, but platoons of vehicles form during the red phases at signalized intersections. In travelling downstream from an intersection, these platoons tend to disperse, but inevitably, some intersections receive incoming platoons rather than fully spread-out vehicle streams. If these platoons are "caught" by a red light, a great deal more delay (in passenger hours) will result than if they pass unimpeded through an intersection during the green phase. The simulation portion of TRANSYT simply estimates the extent to which platoons are caught at each intersection and the resulting total delay in the system, given the fixed characteristics of flow, signal timings, and network geometry. Used by itself, it can depict the consequences of user-specified changes to each of these system features, but its primary application is in conjuction with the optimzation sub-model.

The TRANSYT optimizer essentially seeks to minimize delay in the system by selecting the best signal settings for platoons travelling in each direction. It does so by systematically varying the signal timing parameters, including progression and red/green splits, in search of the "global" minimum for a performance index. The British version uses a simple performance measure:



PHYSICAL CHARACTERISTICS
FLOW PATTERN
SIGNAL TIMINGS
SIMULATION SUB-MODEL
SIMULATION OUTPUT
NO
STOP
OPTIMIZATION ?
YES
OPTIMIZATION SUB-MODEL
OPTIMIZATION OUTPUT
END

FIGURE 3.3

TRANSYT Program Logic

$$PI = \sum_{i=1}^{n} (d_i + ks_i)$$

where:

$PI$ = performance index

$i$ = link index

$n$ = number of links

$d_i$ = delay on link i (i.e., travel time)

$s_i$ = stops on link i

$k$ = weighting factor

At several intermediate points and after finishing the optimization, TRANSYT re-simulates system performance for the revised signal settings.

The basic model has been extended in several important ways (39):

- expansion of the performance index to distinguish the delay and number of stops for priority versus non-priority vehicles, and to represent fuel consumption and emissions explicitly;
- addition of fuel consumption and air pollution sub-models to the basic simulation model;
- inclusion of a "demand response" component to reflect the likely route and mode shifts resulting from certain strategies. The revised program logic with demand response is shown in Figure 3.4.

These modifications have been directed at making TRANSYT a more flexible, comprehensive, and accurate tool for both planning and design.

TRANSYT outputs are designed to assist the analyst in identifying the most serious design deficiencies and in formulating remedial transportation measures. In addition to optimal signal settings at each node, a full range of impacts and travel characteristics is provided for

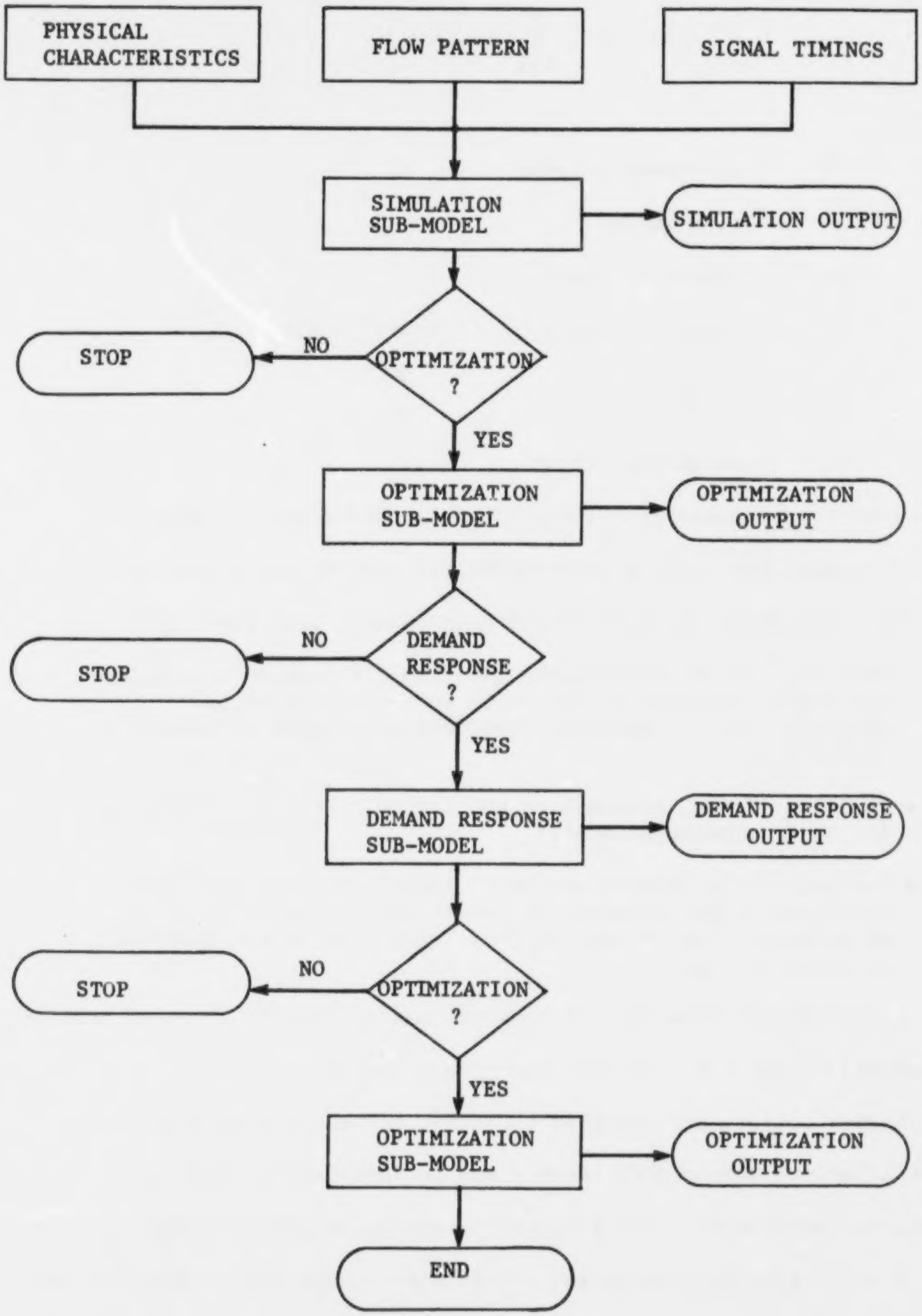

PHYSICAL CHARACTERISTICS
FLOW PATTERN
SIGNAL TIMINGS
SIMULATION SUB-MODEL
SIMULATION OUTPUT
STOP
NO
OPTIMIZATION ?
YES
OPTIMIZATION SUB-MODEL
OPTIMIZATION OUTPUT
STOP
NO
DEMAND RESPONSE ?
YES
DEMAND RESPONSE SUB-MODEL
DEMAND RESPONSE OUTPUT
STOP
NO
OPTIMIZATION ?
YES
OPTIMIZATION SUB-MODEL
OPTIMIZATION OUTPUT
END

FIGURE 3.4

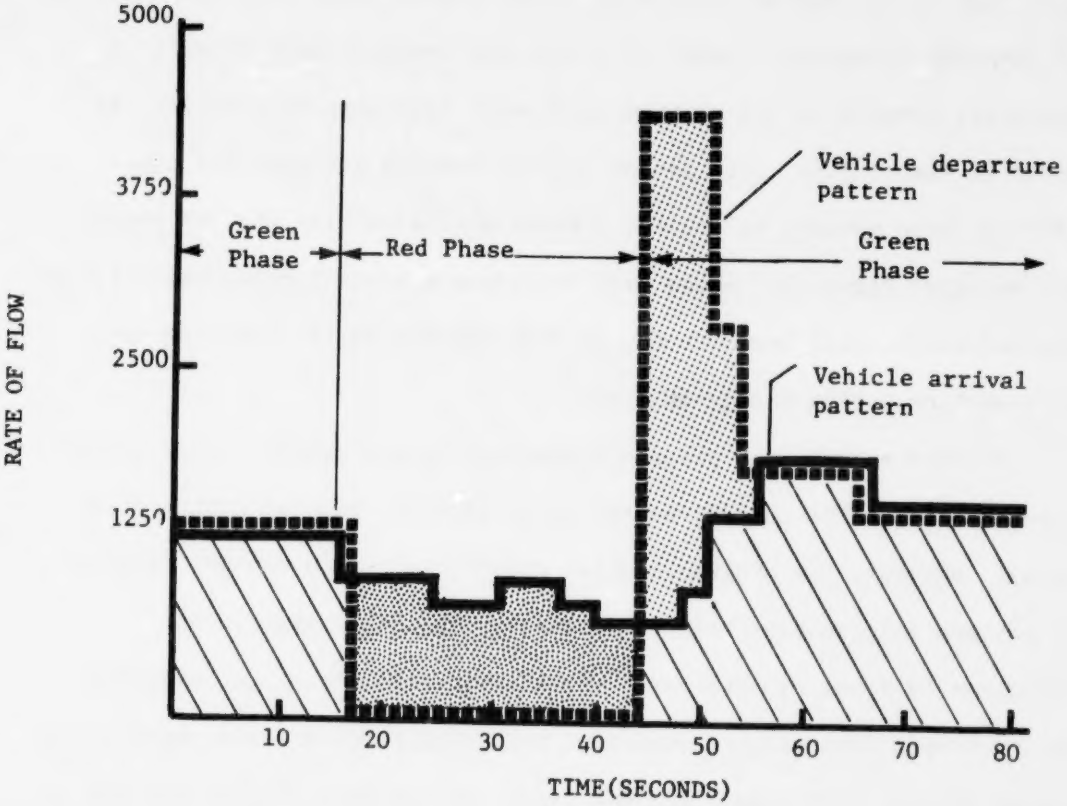
Revised TRANSYT Program Logic

each link in the system, including actual travel time, fuel consumed, HC, CO, and NOx emissions, number of stops, and maximum queue length. A pictorial version of the platooning on each link also is provided, as shown in Figure 3.5. This can be used to examine how well the signal settings have managed to prevent platoon arrival during the red phase. For example, Figure 3.5 shows that the minimum arrival rates occur during the red phase, with the platoon, or what remains of it, reaching the intersection during the green time.

TRANSYT outputs and program documentation are geared toward certain transit/shared ride incentives for local streets, and bus contra-flow lanes. However, the program applies equally to a much broader range of street and intersection-related measures. The basic simulation/optimization model can represent any traffic engineering improvements which affects intersection capacity, including turning lanes, additional signal phases, stop signs, and the like. In addition, it can reflect changes in exogeneous factors, such as general increases in flow and new traffic generators. Table 3.4 illustrates some of the output capability of TRANSYT for a range of measures.

A number of assumptions and limitations are important for some applications of TRANSYT:

- only signalized intersections and side street stop sign controlled intersections are modelled;
- all intersections must have the same cycle length and only one cycle length can be evaluated in each computer run;
- traffic enters the network at a constant uniform rate;



Legend:

▩ Vehicles arriving during "red" phase

▧ Vehicles arriving during "green" phase

░ Vehicles which arrived during "red" phase and waited in a queue

FIGURE 3.5

Display of Platoon Formation at a Traffic Signal Adapted from TRANSYT Output

IMPACTS[1]

| | Time Spent (pass-hr.) | | Fuel Consump. (gal.) | | Vehicle Emission (kg.) | | Mode Shift (pass-mi.) | | Product. (pass-mi.) | | Bus Time Spent (pass-hr.) | | Bus Fuel Consump. (gal.) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ALTERNATIVE | ST | LT | ST | LT | ST | LT | ST | LT | ST | LT | ST | LT | ST | LT |
| Signal Optimization Vehicle Delay | -9 | +1 | -6 | +3 | -9 | 0 | — | 0 | — | +15 | -5 | 0 | -6 | 0 |
| Signal Optimization Passenger Delay | -9 | +1 | -5 | +2 | -9 | +1 | — | 0 | — | +15 | -6 | -1 | -9 | -4 |
| Reversible Lane | -7 | +1 | -3 | +4 | -7 | +2 | — | 0 | — | +16 | -1 | 0 | -1 | -1 |
| Bus Lanes | +58 | +2 | +32 | +3 | +50 | +2 | — | +1 | — | -2 | -13 | -13 | -22 | -23 |

---

[1] Definitions of Impacts:
All percentage changes are with respect to existing conditions:

Time Spent - % change in passenger-hours for all vehicles
Fuel Consump. - % change in gallons of fuel consumed for all vehicles
Vehicle Emission - % change in total vehicle emissions
Mode Shift - % change in passenger-miles for buses
Product. - % change in productivity (passenger-miles) on study arterial
Bus Time Spent - % change in bus time spent in passenger hours
Bus Fuel Consump. - % change in gallons of diesel fuel consumed by buses
ST - short term results
LT - longer term results

TABLE 3.4

Impact Changes Due to Traffic Management Strategies
For Base Conditions

- percentage of turning traffic at all nodes remains constant throughout the simulation period;
- total traffic entering a node equals total traffic leaving a node;
- vehicles queued at the intersection are assumed to be stored vertically; i.e., queues from one intersection are assumed not to interfere with the upstream intersection;
- the demand response has not been validated thoroughly against field data;
- the emissions and fuel consumption models have not yet been updated to 1979 values.

The basic TRANSYT simulation/optimization model has proven accurate and efficient in applications all over the world. These limitations do not alter that basic fact, but they should serve as a reminder that each use of an anlysis method must be accompanied by an appraisal of the assumptions which may be violated in a specific problem context.

### 3.3.2 FREQ

FREQ is a computer model which simulates traffic behavior in a freeway corridor (40, 16). Six generations and many sub-variations of the model have emerged over the past eight years, with successively more comprehensive representations of the freeway corridor, including parallel arterials, demand responses, and fuel and emissions sub-models. Recent versions have been adapted to deal explicitly with measures such as preferential lanes and ramp metering.

As with TRANSYT, FREQ requires a detailed specification of network geometry, origin-destination flows, and freeway operating policies. Input supplied by the user include:

- "time slices" defined to capture the distinct phases of freeway flow--typically 15 minutes each, so that a peak period might consist of 10 to 12 time slices.
- "subsections" defined as the distinct segments of the freeway under study, as in Figure 3.6. Only one direction of freeway flow is studied at a time, and no more than 40 subsections may be included.
- for each subsection:
  - number of lanes
  - capacity
  - length
  - a truck factor (percentage of vehicles which are trucks)
  - a volume delay curve
  - subsection gradient
  - subsection surface quality index
  - ramp capacities
- origin-destination volumes for autos and buses.
- miscellaneous run parameters, depending on the exact FREQ version and analysis circumstances.
- if a parallel arterial is being analyzed:
  - subsection data for each of its subsections
  - base case flow on each of its subsections

Origins and destinations are defined as in Figure 3.6. For this simple example, four flow values would be supplied (1-1, 1-2, 2-1, 2-2). Because it is not easy to obtain these data in practice, methods are available elsewhere for synthesizing the O-D tables from traffic counts at each of the on- and off-ramps and the mainline entry and exit points.

The FREQ simulation focuses on vehicle behavior in each time slice. It first computes the section-by-section flows which are implied by the origin-destination tables. Then it analyzes subsection capcities in light of limiting factors such as weaving and merging. Then, given the flows and modified capacities, it computes travel times by subsection, as well as speeds and vehicle densities at points along the freeway. Finally, it produces fuel consumption and emissions calculations by subsection, and prints the results for the current time slice. After processing all time slices (sequentially) in this manner, it prints a run summary. This sequence is outlined in Figure 3.7.

Simulation alone is sufficient for most FREQ applications, but there are some measures which require a more design-oriented use of the program. One such measure is ramp metering, for which FREQ can predict the necessary metering rates at the various ramps, and the effect on parallel routes. This entails a considerable increase in the program's complexity, as shown in Figure 3.8. The basic model now resides in a loop which is executed four times after the initial simulation of base conditions. On the first pass, optimal metering rates are computed based on flows from the initial simulation, and the flows are re-simulated using, in effect, the new ramp capacities. On subsequent passes, three

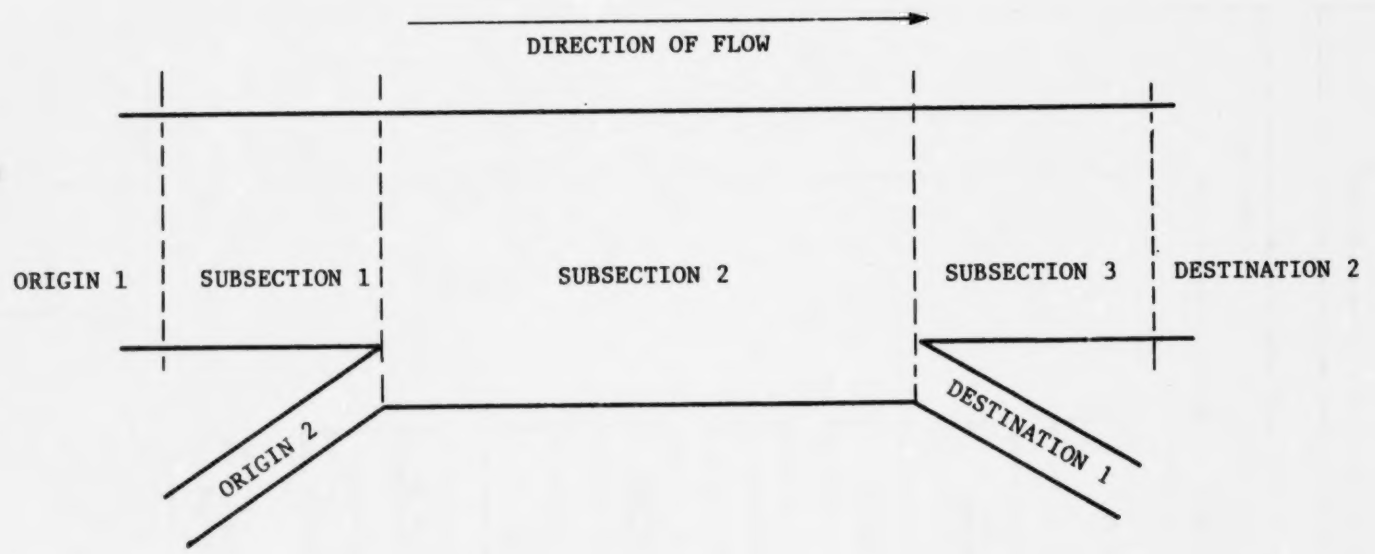

DIRECTION OF FLOW
ORIGIN 1
SUBSECTION 1
SUBSECTION 2
SUBSECTION 3
DESTINATION 2
ORIGIN 2
DESTINATION 1

FIGURE 3.6

Freeway Geometry Definitions for FREQ

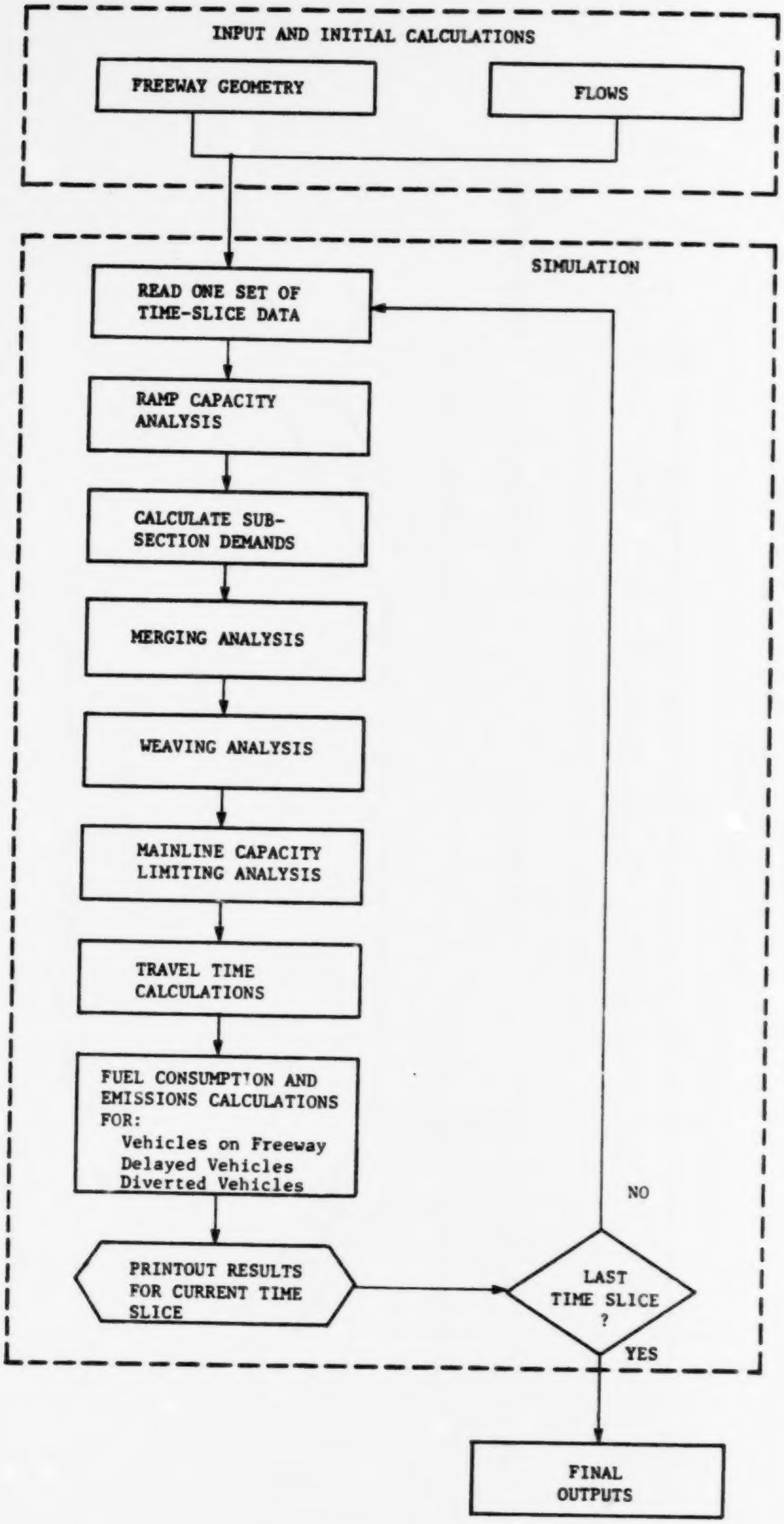

INPUT AND INITIAL CALCULATIONS
FREEWAY GEOMETRY
FLOWS
SIMULATION
READ ONE SET OF TIME-SLICE DATA
RAMP CAPACITY ANALYSIS
CALCULATE SUB-SECTION DEMANDS
MERGING ANALYSIS
WEAVING ANALYSIS
MAINLINE CAPACITY LIMITING ANALYSIS
TRAVEL TIME CALCULATIONS
FUEL CONSUMPTION AND EMISSIONS CALCULATIONS FOR:
Vehicles on Freeway
Delayed Vehicles
Diverted Vehicles
PRINTOUT RESULTS FOR CURRENT TIME SLICE
LAST TIME SLICE ?
NO
YES
FINAL OUTPUTS

FIGURE 3.7

Schematic View of FREQ Simulation Procedure

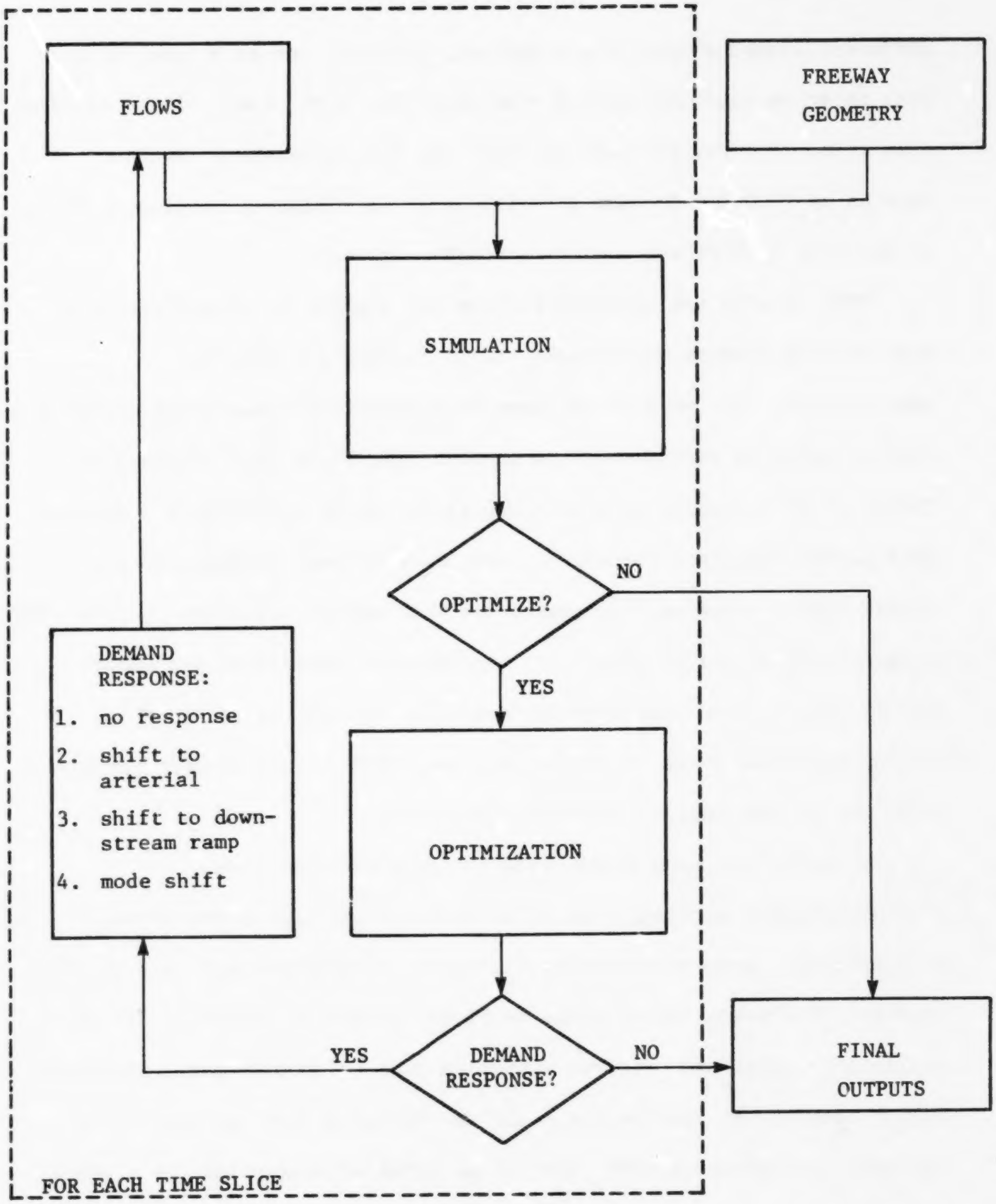
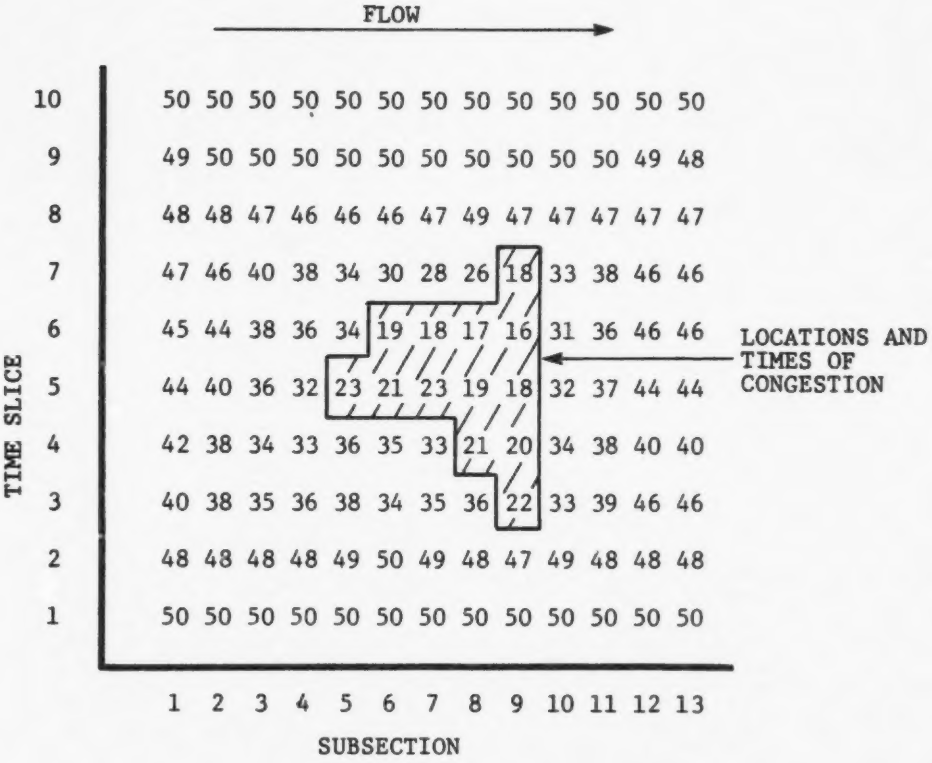

FLOWS
FREEWAY GEOMETRY
SIMULATION
OPTIMIZE?
NO
YES
OPTIMIZATION
DEMAND RESPONSE?
YES
NO
FINAL OUTPUTS
DEMAND RESPONSE:
1. no response
2. shift to arterial
3. shift to downstream ramp
4. mode shift
FOR EACH TIME SLICE

FIGURE 3.8

FREQ Priority Entry Optimization Procedure different demand responses are assumed to occur, one at a time, with a ramp metering optimization and simulation for each case. After the final simulation (for revised mode shares), the run terminates. Another version of FREQ for freeway priority lanes is similarly complex, although it employes a different demand-responsive scheme.

FREQ outputs are intended to help the analyst in identifying the most serious freeway bottlenecks and in formulating remedial improvements. The program produces "speed-contour" maps which depict the average speed on each subsection in each time slice (see Figure 3.9). Speeds of 25 and under on such a map imply demand in excess of capacity (and guaranteed queue formation), and the downtream boundary of the queued region invariably indicates the bottleneck's location. Other FREQ outputs include travel time, fuel consumption, emissions, and number of queued vehicles for each subsection and for the freeway as a whole. In the optimization loops, these outputs are available after each simulation step, or for the initial and final steps only.

In one of its many forms, FREQ can model virtually any freeway-oriented strategy, but it is suited particularly for three applications: ramp entry control, priority treatments, and sensitivity analysis of freeway travel times to flows and design features. In past appliations, FREQ has required extensive data collection and calibration (which consists of running the model and "fine-tuning" the capacities to achieve correspondence with observed patterns of congestion), but these efforts have paid off in an extremely accurate and inexpensive (for simulation) analysis tool. In fact, a before-and-after analysis of the



| TIME SLICE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| 9 | 49 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 49 | 48 |
| 8 | 48 | 48 | 47 | 46 | 46 | 46 | 47 | 49 | 47 | 47 | 47 | 47 | 47 |
| 7 | 47 | 46 | 40 | 38 | 34 | 30 | 28 | 26 | 18 | 33 | 38 | 46 | 46 |
| 6 | 45 | 44 | 38 | 36 | 34 | 19 | 18 | 17 | 16 | 31 | 36 | 46 | 46 |
| 5 | 44 | 40 | 36 | 32 | 23 | 21 | 23 | 19 | 18 | 32 | 37 | 44 | 44 |
| 4 | 42 | 38 | 34 | 33 | 36 | 35 | 33 | 21 | 20 | 34 | 38 | 40 | 40 |
| 3 | 40 | 38 | 35 | 36 | 38 | 34 | 35 | 36 | 22 | 33 | 39 | 46 | 46 |
| 2 | 48 | 48 | 48 | 48 | 49 | 50 | 49 | 48 | 47 | 49 | 48 | 48 | 48 |
| 1 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |

FIGURE 3.9

An Idealized Speed Contour Map From FREQ

(Each number in the map represents the predicted speed (in miles per hour) at a specific time and location.)

Santa Monica Diamond Lane in Los Angeles was remarkably close to what actually occurred (16). Thus, FREQ has considerable "up front" costs, but is a perfectly valid sketch planning and design tool afterwards.

# CHAPTER 4 IMPACT ANALYSIS TECHNIQUES

A number of sketch planning techniques are available for estimating the emissions and energy impacts of measures, once their transportation impacts have been determined using the techniques described in earlier chapters. In fact, a number of the methods described in the previous chapters have been integrated with procedures for estimating emissions and energy impacts. For example, the manual pivot-point worksheets (see Appendix A), the 3MODE(VAN)-AGG calculator method (see Appendix D), and SRGP (6) all have capabilities for producing these impact estimates. For example, a version of SRGP recently has been integrated with the MOBILE1 model (30), which is described in more detail in this chapter. Other procedures, including manual approaches, have been documented by USDOT and EPA (70).

Fewer truly sketch planning approaches exist for estimating other social, economic, and environmental effects. Often the transfer of results from other areas will be the only practical approach unless the resources are available to address these impacts in more detail. A number of studies have dealt with a broad range of impacts of various measures; and again, EPA has provided references to many of these analyses (70).

Four methods for estimating emissions or energy impacts are discussed in this handbook:

- a manual automotive emission estimation method;
- a manaual automotive fuel consumption/operating cost technique;
- calculator programs for bus emission and energy consumption;
- the MOBILE1 emission factor computer program.

The first two methods illustrate how impact worksheet methods can be integrated with manual methods of estimating changes in travel demand. They are summarized in this chapter and presented in complete detail in Appendices D and E. The other two methods are summarized briefly.

## 4.1 Automotive Emissions Estimation Procedure

A method is presented in a set of worksheets for calculating the hydrocarbon, carbon monoxide, and nitrogen oxide emissions associated with changes in automobile travel. The emissions estimation technique can be used in conjunction with manual or other travel demand methods to forecast the impacts on emission levels of a variety of transportation control strategies. It is based on procedures recommended by FHWA and EPA (70). The technique produces estimates based both on the number of trips and the number of vehicle miles of travel in the area under study. Since transportation control policies are not expected to result in significant changes in the number of automobiles owned or operated within a given study area, emissions related to auto ownership levels are not considered.

Incorporated into the technique are calculations of emissions associated with three aspects of vehicle operations: (1) trip-related cold-start emissions; (2) trip-related hot-soak or evaporative emissions; (3) emissions related to vehicle miles of travel.

The method is designed to accommodate data which has been disaggregated by market segment or population subgroup. In addition, stratification into work and non-work trips is recommended for each component of the estimation technique. VMT-related emissions should be calculated separately in the case of subgroups for which average trip distances and/or speeds vary.

Appendix D presents complete information, including worksheets, tables and calculation procedures, which can be used to exercise this emissions estimation procedure.

## 4.2 Automotive Fuel Consumption and Operating Cost Estimation Procedure

Detailed procedures for estimating automotive fuel consumption and operating costs in an urban analysis area context, as a function of the distribution of vehicle weights, average trip length and speed, and ambient temperature have been developed previously and programmed as part of computerized travel prediction methods (8). These procedures have been simplified to be suitable for hand calculation for inclusion in this handbook. In Appendix E, the method is presented in a step-by-step fashion which can be followed to obtain estimates of automobile fuel consumption and operating costs for base cases and policy alternatives which have been analyzed using the pivot-point demand estimation worksheets,[1] or other procedures which provide average trip distances and times. The method can be used for various breakdowns of total travel, such as for separate population subgroup and/or trip purpose segments, or for total travel. The basic procedure calculates fuel consumption and operating costs per trip; the results can be multiplied by number of trips to obtain totals per analysis area.

The inputs required to apply the method are listed in Table 4.1, along with default values based on 1976 conditions. Various sources from which these input values may be obtained for particular localities and analysis years are also indicated. The method is based on urban area travel data in the 10 to 40 mile per hour speed range, and does not represent the decreased fuel economy which occurs at speeds greater than 40 miles per hour.

---

[1] These worksheets are included in Appendix A and are described in Section 3.1.1.

## TABLE 4.1

## Inputs to the Automobile Fuel Consumption and Operating Cost Procedure

| Variable Name | Description | Defaults (1976 Conditions) | Source |
|---|---|---|---|
| **I. General, Related to Fuel Consumption** | | | |
| WT | Average passenger vehicle weight (1000 lbs) | 3.96 | local vehicle fleet data (6, 3) |
| RFC | Impacts of all technological factors but vehicle weight on fuel consumption, relative to 1975 technology (ratio of analysis year fuel consumption to 1975 fuel consumption when vehicle weight reamins constant) | 1.00 | EPA data on fuel economy vs. vehicle weights |
| TEMP | Average ambient temperature (degrees celsius) | 10 | local weather data |
| **II. General, Related to Operating Costs** | | | |
| GCOST | Gasoline cost (dollars/gallon in analysis year dollars) | 0.60 | local gasoline sales data |
| RMTCOST | Repair, maintenance, and tire costs (dollars/mile in analysis year dollars) | 0.03 x 97 | Bureau of Labor Statistics (68) |
| **III. Population Subgroup and Trip Purpose Segment-Specific** | | | |
| TIME | Average one-way trip time (minutes) | - | Worksheet VI |
| DIST | Average one-way trip distance (miles) | - | Worksheet I |
| TPHH | Daily trips per household made by the group (daily one-way trips/household) | - | Worksheet I or VI-A |
| HHS | Total households in the group (households) | - | local data, Worksheet I |

## 4.3 BUSPOL and ENERGY (48)--Environmental and Energy Impacts of Bus Operations

Two calculator programs have been developed for use in predicting the pollution and energy consumption impacts of existing or proposed bus operations. Program ENERGY computes:

- the number of vehicles required on a route given its travel time and the desired schedule
- layover time, given the schedule and number of buses
- total round trip time for each vehicle as well as per mile fuel consumption rates

Vehicle-miles travelled per hour and total fuel consumption per hour of operation are then calculated. The per-mile fuel consumption is determined by route, grade, and operating speed. The effective operating speed is computed based on the specified values of the distance and travel time on the route. The program does not calculate the energy impacts of operating policies on auto or other modes.

Program BUSPOL calculates bus air pollutant emissions as a function of bus operating speed and total vehicle miles operated, on a system or route basis. The emissions rates for diesel buses used in the model are based on EPA data (31). The current version of the model assumes that all buses are operating in the "warm-up" condition, and that all buses in the fleet were manufactured prior to the 1973 model year. Both of these programs are illustrated in Case Study III, Volume II.

## 4.4 MOBILE1 (30) - Motor Vehicle Emissions

MOBILE1 is a computer program that calculates composite emission factors for hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx) from motor vehicles. The program includes the most recent emissions factors and methodology developed by EPA and yet provides the user with the flexibility to vary basic assumptions about deterioration rates for emission control devices and the timetable by which new vehicle emission standards are implemented. The program calculates composite emission factors for three regions:

- low altitude,
- California,
- high altitude (higher than 4000 feet),

and considers six vehicle types. Composite emission factors can be generated for each year from 1970-1999.

Required input data include:

- year of desired emission factor
- percentage of vehicles operating cold (with and without catalysts)
- percentage of vehicles operating in the hot transition phase
- speed
- temperature

Results are quite sensitive to the assumed percentage of vehicles operating cold, moderately sensitive to speed and temperature assumptions, and relatively insensitive to the assumed percentage of vehicles operating in the hot transition phase. Reasonable information on cold operation percentages is available (28) and the percentage of daily VMT operating cold can range from 15 percent in larger cities to as much as 40 percent in smaller urban areas.

If good local data are available, MOBILE1 also allows the user to input such data as vehicle mix and vehicle age distribution. Default values are based on national data and represent reasonable assumptions where local data are not available.

# CHAPTER 5 DESIGNING AN ANALYSIS APPROACH

The preceding chapters in this handbook describe a variety of sketch planning techniques which are available for transportation-air quality analysis. The usefulness of each technique depends on many factors, including data availability, staff skills, study schedule and deadlines, and the particular measures being considered. Thus, one should not expect that one or two methods will be able to handle al of the analysis tasks facing the typical MPO. Rather, an overall program for planning and analysis must be developed, utilizing an array of sketch planning approaches to meet the specific conditions at hand. To do a credible job of analyzing a range of transportation-air quality measures requires that careful priorities be set for both the specific measures, or combinations of measures, that are considered and the specific techniques, or combinations of techniques, that are used at various stages of the planning process.

This chapter provides guidance on how to develop a work program for the analysis of transportation-air quality measures and, in particular, how to judge the appropriateness of the various methods described in this handbook for a specific analysis task. A number of topics are addressed, including:

- developing an analysis strategy and selecting techniques
- representing transportation system changes in analysis techniques
- market segmentation
- data sources
- sensitivity and accuracy

While it is impossible to develop a list of techniques which are always appropriate for analyzing a given transportation measure, each of the factors listed above influences the selection process and provides the analyst with a set of criteria for judging the appropriateness of one or more methods for a specific analysis task.

## 5.1 Developing an Analysis Strategy and Selecting Techniques

A host of factors must be addressed in developing an overall strategy. These factors include:

- overall analysis budget, including staff resources
- staff skills
- methodologies currently in use
- basic analysis approach (e.g., successive cycles of analysis and screening of potential measures)
- study schedule
- data availability
- range of measures under consideration and relative priority of measures
- stage of planning for each measure (i.e., initial consideration versus detailed design)
- type of impacts expected and impacts of most concern
- level of detail required including degree of market segmentation, facility versus corridor or areawide impacts, etc.

Generally, all of these factors will place constraints on the techniques which can be used in a particular context and will dictate the subset of techniques from which the most appropriate method, or methods, for analyzing specific measures will be chosen.

The first five factors represent key constraints on the development of an overall analysis strategy. Budget and staff resources may limit the number of measures examined, the impacts considered, and the level of analysis detail, as well as the specific methodologies employed.

Staff skills and the analysis methods currently being used also may influence the anaysis strategy adopted. If there is limited familiarity with computer techniques, the simpler calculator and manual methods will be more appropriate. Similarly, if staff has some experience with the analysis or implementation of particular measures, the transfer of experience may suffice for these measures while more sophisticated analysis methods are used for less familiar measures. Methodologies already being used, whether true "sketch planning" approaches or not, will probably be adequate for addressing some measures and again may dictate the priorities for acquiring additional analysis methods.

The basic analysis approach may vary from a detailed consideration of a few measures to a broader initial screening of a range of measures. In many cases, several cycles of analysis, each successively more detailed, will be an efficient means of considering a broad range of measures while reserving sufficient resources to analyze the most promising measures in more detail. Again, the appropriate analysis methods will vary depending on the approach adopted. The range of methods documented in this handbook is sufficient to tailor the techniques used to the cycle of analysis being performed. Transfer of experience and other manual and simple calculator approches can be used for an initial screening while other calculator and computer assisted approaches may be used for more detailed evaluation. Obviously, schedule constraints may limit the number of cycles of analysis that are appropriate and therefore the methods that can be used. However, even where time constraints are tight, an initial "broad brush" analysis may be critical to setting priorities for more detailed evaluation.

Data availability is also a critical determinant of the types of analyses that can be performed. The methods presented in earlier chapters vary widely in their data requirements, and some of the techniques are oriented toward developing certain base case data items were none exist. In addition, many data sources not typically used in longer range transportation planning analyses are available for the more flexible analysis requirements of a sketch planning approach. Section 5.5 discusses some of these sources in more detail.

The range of measures being considered and the stage of planning (from initial consideration to detailed design) for each measure has a large impact on the set of analysis methods that will be required. Figure 5.1 illustrates eight broad classes of transportation-air quality measures and some of the specific policies or options that are included in each category. These specific options range in scale from localized projects to areawide programs, reflect a number of different objectives and cover a variety of potential impacts. The broader the range of measures being considered, the fewer the analysis resources that will be available for any one measure. On the other hand, the closer a measure is to being implemented, the more detailed the analysis ought to be. Again, the benefits of performing a number of cycles of analysis, tailored to the range of measures being considered and the implementation status of each measure, are indicated. In general, a broad range of measures will have to be given at least some consideration and the implementation status of each measure will vary. Thus, a variety of analysis methods will have to be employed. Often, a measure showing sufficient potential during an initial screening will have to be analyzed with increasingly detailed methods in subsequent analysis cycles.

FIGURE 5.1

## Representative Actions Within Eight Classes of Transportation-Air Quality Measures

### 1. Automobile-Restricted Zones

- auto-free zones/pedestrian malls
- peak-period auto restrictions in congested areas
- auto restrictions with transit and pedestrian improvements

### 2. Priority Treatment for High Occupancy Vehicles (HOVs)

- HOV lanes on freeways
- parking privileges for HOVs
- preferential treatment for HOVs at toll booths
- signal pre-emption for transit vehicles

### 3. Traffic Flow Improvements

- signal timing improvements
- ramp metering

### 4. Transit System Improvements

- fare reductions
- bus lanes or other priority treatment
- increased frequency of service
- improvements in operations

### 5. Parking Programs

- peak period parking restrictions
- freeze on parking supply
- parking price structure to favor short term occupants over all-day occupants

### 6. Pricing Policies to Discourage Low-Occupancy Auto Travel

- differential tolls or parking prices favoring HOVs
- congestion passes
- increased gasoline tax

### 7. Programs to Encourage Carpooling and Vanpooling

- areawide ridesharing promotion and matching programs
- employer-based ridesharing programs
- incentives for carpools and vanpools, including preferential parking, preferential treatment, no-toll policies, etc.

### 8. Alternate Work Hours

- four day, 40-hour work week
- flextime
- staggered work hours

In reviewing the range of measures that must be analyzed in a particular study, key criteria for selecting a set of analysis methods are the type of impacts anticipated from the measures and the degree of detail desired in the results of the analysis. Throughout this handbook, techniques have been classified as being primarily demand (travel behavior), supply (facility operations), or non-transportation impact (e.g. emissions, energy, etc.) oriented. As described in Chapter 1, this classification was adopted because many transportation-air quality measures can be analyzed by either primarily focusing on demand effects with less emphasis on facility operations, or primarily on facility operations with less attraction to traveller behavior. For example, traffic flow improvements and certain HOV priority treatment measures may affect primarily facility operations and vehicular flow, while areawide parking programs, pricing policies, and carpool/vanpool promotion programs may affect primarily traveller behavior. If either facility operating or traveller behavior effects are dominant, particularly for initial screening of a range of measures, one or more of the specific demand or facility operations techniques described in this handbook can be selected.

Analyses of traffic operations and travel demand often will proceed independently. As a result, demand estimates may depend on level-of-service variables derived from network assignment approaches which employ only order-of-magnitude values of speed stratified by a few broad functional highway classes, or a set of volume versus (average) speed curves representing different highway classes. Often, these estimates are based on personal judgment and scanty empirical data (often from outdated traffic studies) or are obtained from previously coded transportation networks; seldom are rigorous validations of the speed estimates undertaken. On the other hand, highway analyses usually rely on entry to exit flows within the study segment, without regard to actual points of origin and destination. It is difficult to obtain the flow data without detailed field measurements and virtually impossible to predict the effects of operational changes on travel demand. In many cases, these simplifications are justified in a sketch planning analysis. However, for measures for which both traveller behavior and facility operations impacts are expected to be significant, an approach to analyzing supply/demand equilibrium must be developed. For example, designation of an HOV lane may increase both transit and shared-ride mode shares while creating significant traffic flow impacts in the lanes left open to all traffic.

Two approaches for developing an equilibrium analysis framework are:

- use a supply-oriented method and a demand-oriented method iteratively until demand and facility operating impact estimates are consistent
- use one of several methods with a more integrated treatment of supply/demand effects

To represent a measures such as the HOV lane discussed above, for example, initial travel time estimates for high occupancy vehicles and other vehicles using the facility would be used to predict changes in the number of vehicles in each category that would use the facility. From these revised volumes, new travel times could be estimated, and changes in volumes predicted again. This procedure would continue until the difference in travel time estimates for two successive iterations was reduced to within an acceptably small value. Other measures requiring an iterative procedure are those involving resource constraints, such as parking supply, gasoline supply, etc. With these measures, a "shadow time or dollar price" is usually introduced to discourage use of the constrained resource. The magnitude of this shadow price is increased until the demand for the particular resource being constrained matches the amount supplied.

Several of the methods described in this handbook provide a more integrated treatment of facility operations and demand analysis. For example:

- The FREQ series of models uses specified origin-destination flows for the base case, but predicts demand impacts through a set of elasticities derived from logit mode choice models enumerated on a sample of corridor travellers (16, 40).
- A recent application uses demand and supply elasticities at the regional level to predict the joint consequences (and the new equilibrium) resulting from improvements in highway supply (74). With the proper determination of elasticities, it also could be applied to corridors or to more broadly-defined sub-areas of the region.
- A recently developed corridor analysis approach uses a FREQ-type facility model (with multimodal representation), approximate service functions for local streets, and an equilibration scheme (61).

These recent developments reveal a wide range of possibilities for integrating demand and facility operations analysis. Depending upon time and resource availability, and on the type of measure under consideration, a wide range of approaches might be appropriate.

All of the factors discussed above must be considered in selecting techniques to analyze specific measures. In general, it will be desirable to utilize a range of techniques in several cycles of analysis. Obviously, in selecting methods that are consistent with the overall analysis strategy adopted, it is necessary that the techniques be able to represent the measures being considered. In short, the variables included in a method must be capable of representing the significant changes caused by a measure (e.g., change in in-vehicle travel time, out-of-vehicle travel time, out-of-pocket costs, etc.). Table 5.1 provides a summary of the measures that each method, described in detail in this handbook, can address. The best method in any particular context will depend on all the issues discussed earlier as well as the specific design of the measure being considered. Thus Table 5.1 is intended only as a rough guide.

The manual demand methods are generally not appropriate for auto-restricted zones, parking measures (especially supply constraints) and staggered work hours. Some manual demand methods do not explicitly deal with carpooling and/or shared-ride auto usage as a unique mode. This capability is a necessity for the study of high occupancy vehicle priorities, pricing policies to discourage low occupancy vehicles, and carpool/vanpool incentives. The work mode choice worksheet methods are applicable and appropriate for analyzing the largest number of strategies, largely due to their explicit treatment of shared-ride auto travel. Both pivot point (to predict changes from a base case) and synthetic (to predict absolute levels) methods are useful, depending on data availability.

## TABLE 5.1

## Applicability of Demand and Facility Operations Analysis Methods

| METHOD | AUTO RESTRICTED ZONES | HOV PRIORITIES | TRAFFIC FLOW IMPROVE-MENTS | TRANSIT SYSTEM IMPROVE-MENTS | PARKING PROGRAMS | PRICING POLICIES | CARPOOL/ VANPOOL INCENTIVES | STAGGERED WORK HOURS |
|---|---|---|---|---|---|---|---|---|
| Manual Demand | | | | | | | | |
| PIVOT POINT MODE CHOICE | ◕ | ◔ | ◑ | ◑ | ◕ | ◔ | ◔ | ◕ |
| SYNTHETIC MODE CHOICE | ◕ | ◑ | ◑ | ◔ | ◕ | ◔ | ◑ | ◕ |
| QUICK RESPONSE ESTIMATION | ◕ | ● | ● | ◕ | ◕ | ● | ● | ● |
| SYSTEMATIC DATA ANALYSIS | ◑ | ◑ | ◑ | ◑ | ◑ | ◑ | ◑ | ◑ |
| Calculator Demand | | | | | | | | |
| HHGEN | ● | ◑ | ◑ | ◑ | ◕ | ◔ | ◔ | ◑ |
| 2MODE-AGG | ● | ● | ◔ | ◑ | ◕ | ◑ | ● | ◑ |
| 3MODE(VAN)-AGG | ◕ | ◑ | ◔ | ◔ | ◕ | ◔ | ○ | ◑ |
| Computer Demand | | | | | | | | |
| CAPM | ◕ | ◕ | ◑ | ● | ● | ● | ● | ● |
| SRGP | ◔ | ◑ | ◔ | ◑ | ◑ | ◔ | ◔ | ◔ |
| TRANSIT SKETCH PLANNING | ● | ● | ◔ | ◔ | ◑ | ● | ● | ◑ |
| Manual Facility Operations | | | | | | | | |
| TRAFFIC FLOW FORMULAE | ◑ | ◑ | ◕ | ◕ | ◕ | ◑ | ◕ | ◕ |
| GRAPHICAL TECHNIQUES | ◕ | ◑ | ◕ | ◕ | ◑ | ◑ | ◕ | ◕ |
| AREAWIDE TRAFFIC ENGINEERING | ◕ | ◔ | ◔ | ◕ | ◕ | ● | ◕ | ◕ |
| TRANSFER OF EXPERIENCE | ◕ | ◕ | ◕ | ◑ | ◕ | ◕ | ◑ | ◑ |
| Calculator Facility Operations | | | | | | | | |
| BUS | ● | ◕ | ● | ○ | ● | ● | ● | ● |
| Computer Facility Operations | | | | | | | | |
| TRANSYT | ◑ | ◔ | ◔ | ◔ | ◔ | ◔ | ◔ | ○ |
| FREQ | ◔ | ◑ | ◑ | ◔ | ◔ | ◔ | ◑ | ◔ |
| Manual Impacts | | | | | | | | |
| EMISSIONS WORKSHEETS | ◑ | ○ | ○ | ◑ | ◕ | ◔ | ○ | ◔ |
| FUEL CONSUMPTION/OPERATING COSTS | ◔ | ○ | ○ | ◑ | ◕ | ◔ | ○ | ◑ |
| Calculator Impacts | | | | | | | | |
| BUSPOL/ENERGY | ◕ | ◔ | ◕ | ○ | ◕ | ◑ | ◑ | ◕ |
| Computer Impacts | | | | | | | | |
| MOBILE1 | ◔ | ○ | ○ | ◑ | ◔ | ◑ | ○ | ◑ |

KEY

○ GENERALLY APPLICABLE

● GENERALLY NOT APPLICABLE

The calculator demand methods are useful for analyzing HOV priority treatments, traffic flow improvements, transit system improvements, and pricing policies. The effects of these measures generally can be translated readily into changes in modal levels of service. The mode choice methods are well-equipped to predict the effects of modal level of service changes.

For several of the measures, calculator methods can provide only partial results. Parking programs are a good example. On one hand, most parking programs can be translated easily into changes in modal level of service; on the other hand, it is difficult to account for the effects of parking supply on modal level of service changes. Carpool and vanpool incentives generally are handled by calculator methods, but there are some difficulties in specifying the impacts of carpool incentives which do not directly change travel times and costs.

Computerized demand methods are judged to be generally appropriate in terms of the variables and relationships represented, for the widest range of measures. Measures oriented toward high-occupancy vehicles have the fewest applicable methods. The method which deals specifically with the most general breadth of applicability is SRGP. However, SRGP is limited, generally, to large-area measures rather than localized changes.

Facility operations analysis methods are critical for assessing measures and often are important in evaluating ARZ's, transit system improvements, and staggered work hours. Both the manual and calculator supply methods are only sometimes appropriate for most measures, primarily because of their orientation to isolated locations rather than

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to interrelated systems covering the larger geographic areas of concern in a transportation-air quality analysis. Methods of areawide integration of spot or project-oriented procedures are valuable in aggregating their results up to the level required for use in larger geographic scale analyses, but may be limited in appropriateness in some cases if calculator and manual methods are relied upon, rather than computerized techniques, for developing necessary input elasticities. The computerized supply methods are all generally appropriate for analyzing all measures, but it is recognized that the costs of data collection for these models still limits their value for true sketch planning purposes.

## 5.2 Representing Transportation System Changes in Sketch Planning Methods

An important criterion for the selection of specific sketch planning methods is the ability of a method to adequately represent the transportation system changes caused by the measure or measures being studied. In order to adequately represent a measure, the model variables in a method must encompass all the significant transportation changes anticipated. For example, the analysis of the travel demand response to a transit fare or schedule change must be done using a method which includes these transit level-of-service variables. The fare increase would be represented as an increase in transit out-of-pocket costs while an increase in frequency of service would be represented as a decrease in travel time (i.e., a decrease in out-of-vehicle wait time).

If a method does not include those variables likely to be affected by a particular measure, then in general it cannot "represent" such a measure and is an inappropriate technique. In some cases, however, it is possible to represent a measure adequately even if the precise variables affected are not included. In such instances, the variables included in a method must be used as proxies for other changes that occur. For example, parking management measures may affect the supply of parking as well as out-of-pocket costs and travel time. Such supply constraints often can be represented as "shadow cost or dollar prices" on locations where supply is limited. Thus an artificially high parking cost or travel time increment is assumed for the affected locations until the number of travellers selecting those parking locations is consistent with the supply constraint assumed. Travel time increments will be preferred where travel costs have different impacts on different income groups; for example, in models which obtain a cost variable as travel cost divided by household income. In these cases, shadow time costs can be based on available research on the value of time for the average traveller, providing a time/cost tradeoff in which travel time penalities are used to represent "shadow price" increases. In the same way, different components of travel time can be adequately represented by understanding the tradeoff between in-vehicle and out-of-vehicle time.

For those measures that can be expressed in terms of changes in travel time and cost, the representation is relatively straightforward and consists of the following three steps:

1) Identify those travellers affected by the measure (by income, mode, corridor facility, etc.)

2) Identify how these travellers are affected in terms of changes in specific level of service variables.

3) Estimate the magnitude of the level of service changes and the resulting changes in travel demand or facility operating characteristics.

For most measures, those travellers directly affected are easily identified, although with some techniques complications may arise if the measure is to be implemented on a very small scale (e.g. a single facility, one or two blocks in the CBD, etc.). Some measures, though, may have significant indirect effects as well. For example, CBD parking restrictions would have a direct impact on those individuals currently parking within the CBD. While it would be reasonable to expect that many of these individuals would switch to modes other than auto, it would also be reasonable to expect that some would use less convenient parking in fringe areas, increasing the demand for spaces in those areas. Those currently parking in these fringe areas, then, would experience an indirect impact of CBD parking restrictions as fringe area parking became increasingly difficult to find.

When identifying how individuals are affected by a particular measure, it is important to consider the alternative choices available to these individuals. For example, if parking rates are increased for off-street facilities in an area with little free parking available, the appropriate model representation would be the increased rate. If, however, a significant amount of free parking were available in less convenient locations, many individuals may choose to walk farther rather than pay the rate increase. For these individuals, the appropriate representation would be an increase in walk time.

Consideration of alternative responses is also important when estimating the magnitude of level of service changes. For example, if an existing lane on a heavily congested, major expressway is to be reserved for high occupancy vehicles during peak periods, there are a number of ways that those directly affected could respond. One response, of course, would be that intended by such a measure: people would form carpools or use transit to take advantage of decreased travel times afforded by the reserved lane. If this were the only response allowed, the resulting changes in travel times might be quite large. It is likely, though, that many individuals would prefer to use an alternative route rather than change modes. Still others may have the flexibility in choosing their work hours to be able to travel outside the time period of the HOV restriction. To the extent that these alternative responses occur, the impact of the HOV lane in terms of travel time changes would be diminished.

There are a number of measures whose effects cannot be completely expressed in terms of travel time and cost. For example, while auto restricted zones typically result in travel time changes, the enhanced attractiveness of such areas is difficult to quantify. Similarly, variable work hours measures are difficult to represent only using available sketch planning techniques. To analyze such measures, then, empirical evidence such as operational experience also must be relied upon.

## 5.3 Market Segmentation Guidelines

Various factors apart from cost and level of service can cause different subgroups within the population to respond differently to transportation alternatives. Market segmentation is a procedure for dividing, or classifying, the population into a number of discrete groups which exhibit at least some degree of homogeneity with respect to the characteristic(s) of interest. Such classification facilitates analysis of the differential impacts of various measures across different subgroups within the population. The impact of a transportation measure on the travel behavior of individual subgroups or market segments is estimated as a function of changes in cost or level of service. The total aggregate forecast is the weighted sum of the forecasts for each group, where the weights are the fractions of the total analysis population represented by each group. The calculation of separate predictions for various population subgroups not only improves forecasting accuracy but also enables the user to identify measures that would have an inequitable distribution of impacts (e.g. on low income classes).

Among the manual demand techniques which have been reviewed, market segmentation as discussed here is feasible only in the case of the pivot-point and synthetic worksheet methods. The nomographic/formula techniques are not sufficiently flexible to allow for further market segmentation beyond that which is already incorporated into the procedure, and more informal estimation techniques generally are applicable only at a broader, more aggregate level than that suggested in this discussion.

The development of a market segmentation approach for applying the worksheet methods involves a basic tradeoff. On the one hand, the more dimensions along which an urban area population can be classified and the finer the degree of classification, the greater the accuracy and reliability of the resulting predictions. On the other hand, very complex classification schemes require a corresponding increase in the number of computations, increasing the likelihood of an error being made and possibly becoming too complicated and time consuming. Further, base modal shares or even the size of individual classes may not be known with any degree of certainty for a very detailed classification.

Among the classification schemes most appropriate for the pivot-point mode choice method are:

- Modal availability (e.g. transit and vanpool availability)
- Socioeconomic characteristics (e.g. income, auto ownership)
- Trip orientation (e.g. CBD-destined, suburban)
- Pattern of level of service impacts

Modal Availability--Under this classification scheme, the analysis population is categorized according to the travel modes available to the household. For example,

- Drive-alone and shared-ride
- Transit, drive alone, and shared-ride
- Transit and shared-ride
- Drive-alone, shared-ride and vanpool

Classification by modal availability is particularly important. If a classification of this nature is not used, the implicit assumption is that all modes are available to the entire population. In instances where this assumption is invalid, the failure to classify market segments by modal availability can severely bias the analysis results.

Socioeconomic Characteristics--Classification by relevant socioeconomic characteristics reduces aggregation bias and allows explicit evaluation of differential impacts by factors such as income level or auto ownership. To be of maximum effectiveness, the classifications developed should be based on characteristics which produce the greatest variation in travel patterns. For example, if work trip mode choice varies significantly across groups with different auto ownership levels but remains relatively unchanged across different income groups, then auto ownership levels should be used to classify groups.

Regardless of the classification system selected for socioeconomic characteristics, data on existing shares and on changes in transportation level of service for each group are required. Practical problems of data availability may then influence formulation of a classification system.

Trip Orientation--If there is considerable geographic variation in travel patterns, classification of the analysis population by trip orientation can prove effective. While the trip orientation classifications most appropriate for a particular urban area will depend on the area's unique distribution of travel patterns, the greatest differences for many urban areas are found between suburban-to-CBD oriented trips and suburban-to-suburban trips. The former generally have a higher transit share due to better transit level of service relative to auto. Similarly, some differences in travel patterns may exist between individual travel corridors.

Pattern of Level of Service Impacts--The level of service impacts of a particular measure may differentially affect various transportation facilities or services and thus differentially impact their users. Market segmentation by users of specific facilities or services may be appropriate in such cases, particularly if facility operating impacts are expected to be significant or of primary concern. For example, when a high-occupancy vehicle (HOV) lane alternative is analyzed in a travel corridor, separate market segments for freeway users and non-freeway auto users should be considered, since those not using the freeway will only be affected if they change their travel route as a result of the new HOV lane.

## 5.4 Factors Influencing the Accuracy of Sketch Planning Techniques

Any planning decision based on a forecast of future conditions must consider both the predicted impacts of alternative actions and the degree of confidence which can be assigned to the prediction. The analyst must keep in mind the limitations of the techniques being used and the factors which may determine the reliability of the results of the analysis.

Four factors determine the accuracy of impact predictions:

- Accuracy of the input data items
- Level of detail of the analysis
- Appropriateness and reliability of the technique being used
- Transferability of techniques

Depending on the urban area, the measures being analyzed, and the technique in use, the relative importance of the above factors may vary. However, in any analysis, each potentially can play a key role in determining the usefulness of the results.

### 5.4.1 Input Data Accuracy

Although the specific data elements required by the various sketch planning techniques may differ, each requires data from the following categories:

- Travel market segment or population subgroup proportions
- Base case data
- Transportation system changes

Travel market segmentation is a key to the development of an accurate analysis approach because different segments of the population may be expected to be affected in different ways by transportation-air quality measures. The accuracy with which the population can be divided into subgroups or market segments will have a direct influence on the accuracy of the resulting impact forecasts. The accuracy of market segment proportions depends on the availability of up-to-date socioeconomic data (particularly auto ownership and income breakdowns) and a careful assessment of the groups which will potentially be affected by a given measure. For future-year analyses, accurate forecasts of the key variables defining market segments are required. If forecasts must be used, it is likely that the market segmentation approach will be limited by data availability.

Once market segments have been identified, an accurate representation of the base case (existing conditions, or future conditions before any of the measures under analysis take effect) is required. Depending on the availability of data or pnevious forecasts, some elements of the base case data set may have to be estimated as part of the sketch planning procedure. Some of the techniques listed in this handbook include procedures for estimating base-case travel behavior from socioeconomic land use and transportation level-of-service data. Inaccuracies in the data used in these procedures and simplifications inherent in the models themselves are potential sources of error in the base data and the subsequent impact analysis.

The use of pivot-point or incremental techniques avoids the problem of predicting base case travel behavior within the sketch planning procedure and removes the requirement for base transportation level-of-service estimates--both of which are potential sources of significant error. However, their use depends on the availability of data on travel mode choice, and other trip characteristics which are truly representative of the base conditions for the impact analysis. An assessment of the likely accuracy of the results of any analysis must be based on the confidence which may be placed in the base case travel behavior and socioeconomic data, regardless of whether its source is a sketch planning analysis or previous planning work.

The final class of input data required by the sketch planning techniques is the transportation level-of-service changes which are associated with the measures being analyzed. Potential sources of error in the level-of-service impact estimates include:

- under- or over-estimation of the magnitude of the level-of-service impacts of measures,
- failure to consider certain types of impact, and
- inaccuracies in the allocation of impacts among the different groups (market segments) under analysis.

These errors can be minimized by a careful review of the implications of each measure for transportation system performance.

### 5.4.2 Level of Analysis Detail

In general, if the data are available to support it, a more detailed analysis will be more accurate (and also more expensive) than a simple one. For sketch planning techniques, the level of analysis detail is determined largely by the degree to which the travel market is segmented. Given a constant level of accuracy in the input data, the more markets or segments identified, the more accurate the resulting forecast.

Three considerations jointly determine the degree to which market segmentation is used in an analysis:

- Required degree of accuracy
- Budget available for analysis
- Data available for market segments

In many cases the constraint on market segmentation may be the ultimate determinant of analysis detail. Although identifying additional market segments may be beneficial, if too many assumptions must be made to develop the base data for these market segments, little or nothing will be gained in terms of accuracy over a simpler market segmentation scheme. This is not to say that additional market segments should not be identified if assumptions are required to develop base case data for each market segment. If most of the required data items are available and simple assumptions can be used to calculate the missing items from more aggregate base data, it will no doubt be beneficial to proceed with the more extensive segmentation scheme. A certain degree of judgment must go into the design of the market segmentation scheme. The validity of the analyst's judgment may be tested in later stages of the analysis through the use of sensitivity tests, as described in a later section.

Along with the number of market segments identified, the type of classification scheme employed can have a significant impact on the accuracy of predictions developed with sketch planning techniques. As an illustration, consider a proposal to increase bus frequency by 50 percent on all routes in a large city. Although classifying the travel market by auto ownership level would be useful, in this case a more appropriate segmentation scheme would identify and separate those groups which would be affected by the service improvement from those who would not. (Households living in sections of the city not served by transit would not be affected by the proposed change at all.) In developing a market segmentation scheme, it is important to identify those variables which determine how the population will be affected by the measures being evaluated and to classify the market using those variables.

### 5.4.3 The Reliability of Travel Models

Many analysis methods are based on travel models estimated using empirical data. But no model can represent the real world perfectly. Even given very accurate and detailed input data, some error is inherent in the use of any model. Assessing the magnitude of this error is difficult because of the interrelation between input data accuracy and model reliability in determining the accuracy of resulting predictions. Each of the techniques described in this manual has been tested and found to be reasonably accurate relative to other techniques available for sketch planning analysis. In terms of their reliability, many compare quite favorably with any existing technique, as they are based on the same theory found in extensive computer-based model systems. In most instances, the accuracy and level of detail of the data available for use in an analysis will have by far the greatest impact on the accuracy of sketch planning impact estimates.

Although the error magnitudes of models are difficult, if not impossible to assess, the error associated with the models described here can be controlled to some degree by ensuring that the most appropriate model is applied to the measure being analyzed. Ensuring that the model is sensitive to both the level-of-service and travel behavior changes implicit in a given transportation-air quality measure is the first step in finding the most appropriate technique. Section 5.2 provides a more in-depth discussion of the applicability of the sketch planning techniques to specific measures.

### 5.4.4 Sensitivity Testing

While error and uncertainty can be controlled to some degree through careful application of the sketch planning models, they can never be eliminated. In order to assess the probable magnitude of the error of a given impact prediction, sensitivity analyses may be employed. Sensitivity analysis involves redoing all or part of a completed analysis using different values for specific data items or model coefficients while holding all other values constant. In this way, the sensitivity of the impact assessment to an assumption which was necessary to perform the analysis or the value of an input data item which is uncertain can be assessed. A sensitivity analysis can be conducted for a single item or several simultaneously. (Best case and worst case analyses are examples of simultaneous sensitivity tests.)

Although sensitivity tests can be conducted for all of the data items or all the model coefficients used in a particular analysis, it is likely that time and budget constraints will preclude such an approach. In order to assure that the sensitivity analyses conducted are useful, several guidelines should be followed:

- Test those data items which were estimated with the highest degree of uncertainty or for which the most significant assumptions were required.
- Test those variables which will have the greatest impact on the predicted results, as reflected by the size of the model coefficients. Other important items include market segment sizes and base mode shares. Highest priority for sensitivity testing should be assigned to items fitting into both of the above classifications.
- Confine the sensitivity tests to values which may reasonably be expected to occur for the input data items.

- Test only the model coefficients relating directly to the level-of-service change anticipated for the measure under analysis.

- Where two variables are expected to be of similar importance, test the variable coefficient which is less statistically significant first.

A final guideline for sensitivity testing, and for the evaluation of analysis accuracy in general, is to match the level of effort to the requirements of the task being done. For example, during the initial stages of an evaluation of a number of transportation-air quality measures, less accuracy may be required than when detailed feasibility studies are being conducted for one or only a few measures.

### 5.4.5 Transferability

The reliability of transportation analyses depends to a great extent on the quality of travel demand predictions. Many urban areas would find it desirable to improve their travel demand modelling capabilities in this regard. However, in many cases, the development of new models would require a substantial proportion of the total short-range analysis budget--in some cases, it could exceed it. Such resource considerations have motivated the development of a methodology for using a travel demand model developed for one urban area in other settings. This process is called "transferring" a model.

To be transferable, it is not enough that a model merely "fit" existing data; the model must be able to explain how travel behavior will change as conditions change. Explaining how behavior will change is much more likely if we understand why it changes; in other words, we wish to have an understanding (or at least a theory) of the underlying causality. Thus, rather than just correlating existing travel behavior with socioeconomic characteristics (e.g., retail employment in a zone) and transportation level of service, the model "specification", that is, the set of variables included in the model and the relationships among the variables, must represent the causal relationships between these variables. Otherwise, there would be no reason to expect a model to perform well under different conditions, for even a major change in a spuriously correlated variable would not change travel behavior, while a change in an omitted causal factor could be significant (but would not be captured). Thus, causal specification of a model would seem to be a precondition to its consideration for transfer.

From a practical point of view, however, no model is perfectly specified. Often, variables which should be included in the model must be excluded (e.g., when not enough data are available). When data for model development are taken from a single urban area, there may be some cultural differences between urban areas which are not explicitly represented in the model. The peculiarities of the data will be implicitly hidden in the model coefficients which are estimated with the data. Thus, no model developed on such data can be expected to be completely transferable.

Luckily, "perfect" transferability is unnecessary; the model needs only to be sufficiently accurate for practical transportation planning needs. Hence, it is possible that models which are statistically "non-transferable" may be quite adequate for some practical applications. In this sense, transferability is not an absolute to be accepted or rejected, rather, it is a relative attribute dependent not only on differences between coefficients but also on the particular application for which the model is intended.

As an example of a test of the transferability of disaggregate demand models, the coefficients of a mode choice model developed on 1968 Washington, DC data were re-estimated on data sets representative of New Bedford, Massachusetts in 1963, and Los Angeles, California in 1967 (2). The model coefficients resulting from this re-estimation were compared to those originally estimated for the model. A multinomial logit mode choice model was used in this test (5). This model predicts the probability of a commuter driving alone, sharing a ride (i.e., two or more persons in a car), or using transit for the home-to-work trip. The model specification is given in Figure 5.2. The coefficients were estimated using the maximum likelihood method with 1114 observations from a 1968 home-interview survey conducted in Washington, DC. The model coefficients and statistical properties are shown in Table 5.2.

In "transferring" this model to both the New Bedford and Los Angeles data sets, the specification of the independent variables is identical to that of the original model, with the exception that both CBD variables and the government worker variable are excluded. In the case of the CBD variables, the congestion and inconvenience associated with driving into the CBD of a large, dense city such as Washington, are very real factors in choosing between auto modes and transit. In a small city such as New Bedford or a very diffuse city such as Los Angeles, however, the distinction between CBD and non-CBD trips would probably have little added effect on this choice. Therefore, the CBD variables are assumed to have a value of zero. Similarly, the effects of large organizations offering carpool incentives did not exist in either New Bedford or Los Angeles at the time the surveys were administered and therefore the government worker variable takes the value of zero for both of these cities.

The estimation results, the coefficients and statistics of the models estimated on the New Bedford and Los Angeles data sets, are shown in Table 5.2 along with the original Washington coefficients. The coefficients of the New Bedford model all have the correct signs. The 't' statistics, however, are not nearly as large as those of the original

## FIGURE 5.2

## Work Mode Choice Model:

## Definition of Variables

| Variable Code | | Definition |
|---|---|---|
| 1. $D_c$ | = | 1, for drive alone<br>0, otherwise |
| 2. $D_s$ | = | 1, for shared ride<br>0, otherwise |
| 3. OPTC/INC | = | round trip out-of-pocket travel cost (in cents)/ household annual income (in dollars) |
| 4. IVTT | = | round trip in-vehicle travel time (in minutes) |
| 5. OVTT/DIST | = | round trip out-of-vehicle travel time (in minutes)/ one way distance (in miles) |
| 6. $AALD_c$ | = | # of autos/licensed drivers, for drive alone<br>0, otherwise |
| 7. $AALD_s$ | = | # of autos/licensed drivers, for shared ride<br>0, otherwise |
| 8. $BW_c$ | = | 1, if worker is the breadwinner, for drive alone<br>0, otherwise |
| 9. $GW_s$ | = | 1, if worker is a civilian employee of the federal government, for shared ride<br>0, otherwise |
| 10. $DCITY_c$ | = | 1, if work place is in the CBD, for drive alone<br>0, otherwise |
| 11. $DCITY_s$ | = | 1, if work place is in the CBD, for shared ride<br>0, otherwise |
| 12. $DINC_{c,s}$ | = | household annual income--80 x # of persons in the household (in $), for drive alone and shared ride<br>0, otherwise |
| 13. $NWORK_s$ | = | # of workers in the household, for shared ride<br>0, otherwise |
| 14. $DTECA_s$ | = | employment density at the work zone (employees per commercial acre) x one way distance (in miles), for shared ride<br>0, otherwise |

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Alternative: c = drive alone, s = shared ride (car pool), t = transit

## TABLE 5.2

## Transferability of Work Mode Choice Model to Different Cities

| Variable | Coefficient/(t-statistic) | | |
|---|---|---|---|
| | New Bedford | Washington | Los Angeles |
| $D_c$ | -2.198<br>(-2.648) | -3.24<br>(-6.86) | -2.746<br>(-4.85) |
| $D_s$ | -1.535<br>(-1.535) | -2.24<br>(-5.60) | -1.830<br>(-3.95) |
| OPTC/INC | -87.33<br>(-1.576) | -28.8<br>(-2.26) | -24.37<br>(-2.07) |
| IVTT | - .0199<br>(- .4849) | - .0154<br>(-2.67) | - .01465<br>(-2.25) |
| OVTT/DIST | - .1013<br>(-2.903) | - .160<br>(-4.08) | - .1860<br>(-4.02) |
| $AALD_c$ | 2.541<br>(3.674) | 3.99<br>(10.08) | 3.741<br>(7.19) |
| $AALD_s$ | .4499<br>(.8478) | 1.62<br>(5.31) | .6093<br>(1.58) |
| $BW_c$ | 1.026<br>(3.769) | .890<br>(4.79) | .8101<br>(3.28) |
| $GW_s$ | -<br>- | .287<br>(1.78) | -<br>- |
| $DCITY_c$ | -<br>- | - .854<br>(-2.75) | -<br>- |
| $DCITY_s$ | -<br>- | - .404<br>(-1.36) | -<br>- |
| $DINC_{c,s}$ | .000072<br>(1.279) | .00007<br>(3.46) | .000083<br>(2.31) |
| $NWORK_s$ | .1874<br>(1.249) | .0983<br>(1.03) | .0810<br>(.46) |
| $DTECA_s$ | .00060<br>(.7665) | .00063<br>(1.34) | .00027<br>(2.23) |
| # of observations | 453 | 1114 | 879 |
| # of alternatives | 1208 | 2924 | 2549 |
| Log Likelihood at zero | -436.4 | -1054.0 | -930.0 |
| Log Likelihood at convergence | -256.5 | -727.4 | -391.2 |

model, although for only three coefficients (in-vehicle travel time, shared ride auto availability, and employment density times distance) are they seriously low. This relatively poor statistical performance may be partially linked to smaller sample size (453 versus 1114 observations) and the much lower variability observed for several of the level of service variables due to data limitations. (Data were available only for those trips with both origin and destination within the city of New Bedford itself.) For example, average one-way distance (as a proxy for travel time and cost) in the Washington sample was about eight miles. In the New Bedford sample, however, average one-way distance was only two miles. In this case, overall statistical performance is much better than the New Bedford model, due in part to the larger sample size (879 observations).

A comparison of the three sets of coefficients indicates that they are remarkably similar. The signficance of the differences in coefficient values that do exist between models can be evaluated by transforming the coefficient values into elasticities. The elasticities which correspond to the Washington, New Bedford and Los Angeles coefficients are presented in Table 5.3.

Except for the travel cost elasticity for the New Bedford data, all other elasticities are sufficiently similar to warrant the conclusion that even if the model as a whole (and in particular the model constants and socioeconomic variables' coefficients) is not transferable, the level-of-service elasticities evaluated using the Washington coefficients are transferable.

TABLE 5.3

Comparison of Elasticities for Three Mode Choice Models

| Variable | Elasticities Calculated for the New Bedford Sample Means: New Bedford Coefficients | Elasticities Calculated for the New Bedford Sample Means: Washington Coefficients | Elasticities Calculated for the Los Angeles Sample Means: Los Angeles Coefficients | Elasticities Calculated for the Los Angeles Sample Means: Washington Coefficients |
|---|---|---|---|---|
| Out--of-Pocket Cost | | | | |
| Drive Alone | -.092 | -.030 | -.047 | -.055 |
| Shared Ride | -.057 | -.019 | -.092 | -.109 |
| Transit | -.852 | -.281 | -.378 | -.447 |
| In-Vehicle Travel Time | | | | |
| Drive Alone | -.138 | -.107 | -.026 | -.027 |
| Shared Ride | -.315 | -.243 | -.664 | -.695 |
| Transit | -.373 | -.288 | -.653 | -.684 |
| Out-of-Vehicle Time | | | | |
| Drive Alone | -.138 | -.217 | -.027 | -.023 |
| Shared Ride | -.189 | -.299 | -.122 | -.105 |
| Transit | -1.55 | -2.46 | -1.024 | -.881 |

In summary, the fact that the original specification resulted in a reasonable model in other areas, together with the fact that both the sets of coefficients taken together and key elasticities are not significantly different, is encouraging. The differences between several of the coefficients indicate areas where more research on improved specification may prove fruitful, and demonstrate that the comparison of coefficients estimated for two different data sets is a very powerful method of detecting specification errors. But, whatever improvements are implemented, no model will be perfectly specified and therefore perfectly transferable, and hence the motivation for the application of "updating procedures"--correction factors--for the model coefficients.

By far the simplest approach for transferring a model from one urban area to another, and certainly the one requiring a minimum level of effort, would be to use the existing model with its original coefficients. In doing this, the assumption being made is that all factors relevant to the choice process are embodied in the model, an assumption which will never by fully justified. For example, the specifications of most models available today contain constant terms to account for all other factors not explicitly explained by the model (comfort, convenience, safety, etc.). The presence of these constants indicates that in fact the model has not captured all aspects of the choice process. Because these "other factors" can vary between areas, the value of such a constant estimated in one area may or may not be appropriate for another area. Therefore, although there is theoretical justification for transferring the relationships estimated between time, cost, income, auto availability, etc.--the variables which theory says influence travel behavior--no theoretical basis exists for transferring these constant terms.

Fortunately, in most applications data are available on existing conditions; the model will be used to predict changes in travel behavior as a result of changes in the independent variables. In these applications, only those coefficients associated with the specific variables to be changed need be used. For incremental predictions such as the manual and calculator-based "pivot-point" techniques, there is no need to transfer constant terms.

In some situations, however, data on the existing conditions are not uniformly available at the required level of detail and the constants must be modified. For example, observed transit mode share may be 7 percent, but the transferred model predicts 2 percent. If extensive information were available, it could be used to determine which variables were causing the problem, and therefore should be adjusted. Without such data, a suitable approach might be to use the existing model with adjustments of the alternative-specific constants, variables 1 and 2 in Figure 5.2. In this approach, the coefficients are accepted without change, and either aggregate data on travel patterns or a disaggregate sample with observed choices from the new area would be used to adjust the constants, better reflecting the existing situation. The adjustment is performed by applying the model to the new area in the same way in which it will be applied for forecasting. With aggregate data, model predictions are aggregated to the level for which observed data are available. The constants are then adjusted until the model replicates existing aggregate data.[1] With disaggregate data, choice probabilities for each observation in the sample are summed and compared with the summed observed choices. Constants then are adjusted until predicted shares match those observed. This is the procedure that has been used in adapting SRGP to a number of urban areas (7). A number of other, more complex updating procedures are available, but their application in a sketch-planning context is somewhat limited (2).

---

[1] The following equation can be used to obtain an approximation of the required change in a constant term:

$$\Delta C_m \cong \ln \frac{OBS_m}{PRED_m} \bullet \frac{PRED_b}{OBS_b}$$

where:

$\Delta C_m$ = the required change in the constant term associated with alternative m.

$OBS_{m,b}$ = observed shares of alternative m, and of alternative b, which is that alternative with no constant term.

$PRED_{m,b}$ = predicted shares of alternatives m and b.

## 5.5 Data Sources for Air Quality Analysis

Many of the techniques described in this handbook are flexible in terms of their analytical detail and input data requirements. In order to make the best use of these techniques, the analyst must be prepared to look beyond the traditional sources of transportation planning data. The key to using these techniques is to make the maximum possible use of all available data sources, by tailoring the analysis to the available data as well as the transportation-air quality measure being analyzed.

This section briefly reviews the alternative sources of data which may be available to urban area planners for use in air quality analyses and suggest the ways in which they may be employed. However, because every urban area is unique in terms of the data available for air quality analyses as well as the transportation measures most appropriate for evaluation, it is not possible to specify a step-by-step approach to data gathering and impact analysis.

The guidelines presented in this section are supplemented by the evaluation case studies presented in Volume II, which serve to illustrate the use of a wide variety of data sources and associated analytical techniques. Together, these general guidelines and case studies are intended to define a style of approach to air quality impact evaluation, the details of which are developed by the analyst to fit the requirements of the particular problem to be addressed.

Several basic types of data generally are required for transportation-air quality analyses:

- Existing or base case travel behavior--including travel mode shares, trip lengths, and trip-making frequencies for different trip types.

- Vehicle miles of travel (VMT)--areawide total VMT may be of interest, or it may be necessary to have VMT broken down by trip type, time of day, highway facility type, location, or some combination of the above.

- Socioeconomic data--household auto ownership, income and other socioeconomic data may be of interest, particularly in defining population subgroups for analysis.

- Employment data--many of the transportation measures with potential to address air quality problems are employer-based. For example, ridesharing programs are typically applicable at large employment sites: in this case, employer size data is necessary for air quality impact evaluation.

- Transportation level of service--depending on the analysis technique being used, either base case and revised transportation level-of-service values or level-of-service changes are required. In many ways this can be the most formidable of the data requirements if base case data must be developed. However, this difficulty can be overcome by using the incremental or "pivot-point" techniques described in this handbook which rely strictly on changes in level of service. These changes are relatively easy to estimate based on the specific measures being analyzed.

- Transportation facility characteristics--the analysis of traffic engineering actions as air quality improvement measures requires data on the characteristics of highways and traffic control devices. Also, planned future changes in the transportation system must be accounted for in the analysis of any transportation-air quality measure.

Table 5.4 indicates potential sources for each of the above evaluation data elements. Within particular urban areas, still other sources of data may be available for air quality planning use and should be pursued as appropriate.

The most comprehensive source of planning data in any urban area will be previous planning and transportation modelling work. The quality and level of detail of data available from previous efforts will in many cases be the primary determinant of the analysis techniques to be used in the evaluation of transportation air quality measures. For example, if

TABLE 5.4

Transportation-Air Quality Data Requirements and Sources

| Data Elements \ Data Sources | CENSUS | HOME INTERVIEW SURVEYS | LAND USE PLANNING | EMPLOYERS | STATE EMPLOY-MENT AGENCIES | TRAFFIC COUNTS | TRANSIT OPERATING DATA | ESTIMATION USING MODELS | NOMO-GRAPHIC FORMULAS | PREVIOUS PLANNING AND MODELLING |
|---|---|---|---|---|---|---|---|---|---|---|
| TRAVEL MODE SHARES | ● | ● |  |  |  | ● | ● | ● | ● | ● |
| TRIP LENGTHS | ● | ● |  |  |  |  |  | ● |  | ● |
| TRIPMAKING FREQUENCIES |  | ● |  |  |  | ● |  | ● | ● | ● |
| VMT |  |  |  |  |  | ● |  | ● | ● | ● |
| SOCIOECONOMIC DATA | ● | ● | ● |  |  |  |  |  | ● | ● |
| EMPLOYMENT DATA | ● | ● | ● | ● | ● |  |  |  |  | ● |
| TRANSPORTATION LEVEL OF SERVICE |  | ● |  |  |  | ● | ● | ● |  | ● |
| TRANSPORTATION FACILITY CHARACTERISTICS |  |  |  |  |  | ● | ● |  |  | ● |
| AUTO OWNERSHIP | ● | ● |  |  |  |  |  | ● |  | ● |

extensive and up-to-date data is available in UTPS format and access to a computer is readily available, SRGP (see section 2.3.2) could be effectively employed to analyze a large number of transportation measures. However, if relatively little or no UTPS work has been done, setting up SRGP would be costly and inefficient, suggesting that one of the manual analysis techniques should be employed.

While previous analytical work provides an important input to the air quality planning process, the other data sources shown in Table 5.4 may be used to support reliable analyses, and in many cases will be required to supplement the data from previous work. Each source is discussed briefly below.

Census Data--Information on work travel mode choices and work trip destinations as well as basic socioeconomic data including auto ownership are available from census reports. Case Study III in Volume II provides an example of the use of census data in the evaluation of transit preferential treatment. Additionally, the County Business Patterns report provides employer size and industry employment figures at the county level. At present, the primary weakness of census data is its age. In areas experiencing rapid growth, ten year old census data from 1970 may not be available in time for use in analyzing measures to be included in the 1982 SIP revision. However, in many cases, for general assessment purposes, census data, supplemented by more up-to-date estimates wherever possible, will be adequate.

Home Interview Surveys--A recently concluded home interview survey (HIS) can provide all of the travel data needed for transportation-air quality analysis. Typically, however, it will have been several years since a comprehensive HIS has been conducted. (In many areas the last HIS was conducted in the early- to mid-sixties.) Techniques are available to update survey data to conform with more current data from other sources and even a 10- to 15-year-old HIS can provide useful information on which to base an evaluation.

Lane Use, Economic, and Population Projections--These studies will provide the primary sources of future population and employment projections which must be used to develop base data for other than current or past year analyses. These studies are typically conducted by metropolitan planning organizations as part of their ongoing planning activities. The information available from future-year projections can be used to update any data items not explicitly forecast for future years by using simple relationships between the forecast and non-forecast data items.

Employers--Employers can provide the most comprehensive and up-to-date information on employment in an urban area. Of course, contacting each employer in an area can be quite time consuming, and there is no guarantee that the employers contacted will provide the requested information. An alternative source of employment data, particularly for the CBD of large cities, is a downtown business association. Such an organization may be able to provide an estimated breakdown of employment by category as well as the total employment in the downtown area. This information can be used to supplement data available from the Census' County Business Patterns.

State Employment Services--These agencies may be able to provide more recent county-level employment data than that available from the census, although in somewhat less detail with respect to industries and employer size categories.

Traffic Counts--Traffic counts are typically conducted by city traffic departments as a part of their traffic engineering program. They also are conducted by state highway personnel in many states on major facilities. The coverage and frequency of these counts is variable among urban areas and among cities within urban areas. Traffic counts may also have been conducted in support of transportation modelling efforts in the past.

Transit Operating Data--Transit operators receiving federal funding support are required to maintain operating, revenue and cost data under the Uniform System of Accounts and Records. Among the data which must be maintained are passenger-miles and unlinked passenger trips. Many operators maintain more extensive operating and passenger data for their own use in evaluating service. These more detailed data may be of use in corridor and subarea analyses of transportation-air qualiy measures.

Estimation Using Models--In cases in which previous planning and modelling efforts do not provide the required information, both computer and manual models are available for estimating base conditions, particlarly trip-making characteristics. Some of these models are described in this handbook; examples of their use in developing base case travel behavior estimates are outlined in Volume II. In general, because of the expense and effort involved, these methods would only be used to develop base data if no other source of travel behavior estimates were available.

Nomographs and Formulas--An alternative to the use of models in developing base travel behavior estimates is the transfer of data from similar urban areas through the use of nomograph or formula relationships. This approach may be more desirable in the initial stages of the evaluation of transportation-air quality measures since the use of models can be expensive and time-consuming. An excellent source of data and basic relationships for transfer to an urban area is NCHRP Report 187 (18). The techniques described in this report correspond to the traditional four-step travel behavior estimation process (trip generation, trip distribution, mode choice and assignment) and include time-of-day, auto occupancy, and other supplementary estimation procedures.

It is likely that different data sources will be most appropriate during the various stages of the air quality planning process. At the outset, a large number of candidate measures will be under analysis, and general analytical techniques with limited data requirements will be used to screen out those measures with little or no potential. As the evaluation of candidate actions proceeds, more detailed analysis techniques and supporting data will be required to identify the most desirable transportation measures and to develop effective combinations, or packages, of measures. As the options are narrowed, the impacts of the proposed measures on specific segments of the population may also be of concern, requiring still more extensive data.

In developing an evaluation approach, these varying data requirements must be balanced against the availability of specific data items. In many cases, it will be necessary to estimate some of the more detailed data elements based on the information which is available. If accurate and up-to-date information is not available for certain key data items, sensitivity analyses may be used to bracket the range of impacts which may be used to bracket the range of impacts which may be expected. Again, flexibility in analysis approach and data utilization will be a primary requirement for the development of an effective transportation-air quality program.

# APPENDIX A

## Worksheets for the Manual Pivot-Point Mode Choice Method

The pages which follow consist of copies of the worksheets originally included in Ref. (14), for analyzing the impacts of changes in transportation level-of-service on work mode choice. The use of these worksheets is discussed in Section 2.1.1.a and illustrated in Case Study I, Volume II.

## I. BASE DATA

POLICY: ______

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Daily VMT | Total | | | | | | | | | | |
| | Non-Work | | | | | | | | | | |
| | Work | | | | | | | | | | |
| Average Trip Length | Non-Work (one way) | | | | | | | | | | |
| | Work (one way) | | | | | | | | | | |
| Average Carpool Size | | | | | | | | | | | |
| Base Work Trip Modal Shares | Other | | | | | | | | | | |
| | Transit | | | | | | | | | | |
| | Shared Ride | | | | | | | | | | |
| | Drive Alone | | | | | | | | | | |
| Average Household Data | Number of Non-Work Auto Trips | | | | | | | | | | |
| | Number of Workers | | | | | | | | | | |
| | Annual Income $ | | | | | | | | | | |
| Fraction of Total Population | | | | | | | | | | | |
| Population Subgroup | | | | | | | | | | | |

## I-A. BASE VMT

POLICY: ____________________

SUBGROUP: ____________________

### 1. BASE HOUSEHOLD WORK TRIP VMT

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Base Shared Ride Modal Share | | Base Average Carpool Size | | Base Drive Alone Modal Share | | | | Base Autos Used per Worker |
| | ÷ | | + | | | | = | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Base Autos Used per Workers | | No. of Workers per Household | | Work Trip Length | | | | Base Household Work VMT |
| | X | | X | | X | 2.0 | = | |

### 2. BASE HOUSEHOLD NON-WORK TRIP VMT

| | | | | | | |
|---|---|---|---|---|---|---|
| No. of Non-Work Auto Trips | | Non-Work Trip Length | | | | Base Household Non-Work VMT |
| | X | | X | 2.0 | = | |

### 3. BASE HOUSEHOLD TOTAL VMT

| | | | | |
|---|---|---|---|---|
| Base Household Work VMT | | Base Household Non-Work VMT | | Base Household Total VMT |
| | + | | = | |

## II. CHANGES IN TRANSPORTATION LEVEL OF SERVICE (ROUND TRIP)

POLICY: ____________

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Transit | Out-of-Pocket Travel Cost $\Delta OPTC_t$ ¢ | | | | | | | | | |
| | Out-of-Vehicle Travel Time $\Delta OVTT_t$ min. | | | | | | | | | |
| | In-Vehicle Travel Time $\Delta IVTT_t$ min. | | | | | | | | | |
| Shared Ride | Carpool Promotion & Matching Incentives 0,1 | | | | | | | | | |
| | Out-of-Pocket Travel Cost $\Delta OPTC_{sr}$ ¢ | | | | | | | | | |
| | Out-of-Vehicle Travel Time $\Delta OPTC_{sr}$ min. | | | | | | | | | |
| | In-Vehicle Travel Time $\Delta IVTT_{sr}$ min. | | | | | | | | | |
| Drive Alone | Out-of-Pocket Travel Cost $\Delta OPTC_{da}$ ¢ | | | | | | | | | |
| | Out-of-Vehicle Travel Time $\Delta OVTT_{da}$ min. | | | | | | | | | |
| | In-Vehicle Travel Time $\Delta IVTT_{da}$ min. | | | | | | | | | |
| Population Subgroup | | | | | | | | | | |

## II-A. CHANGES IN TRANSPORTATION LEVEL OF SERVICE BY CARPOOL SIZE

POLICY: ____

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Changes in Transportation Level of Service (Round Trip) | 3+ Person Carpool | Promotion and Matching Incentives 0,1 | | | | | | | | | |
| | | Out-of-Pocket Travel Cost $\Delta OPTC_{3+}$ | | | | | | | | | |
| | | Out-of-Vehicle Travel Time $\Delta OVTT_{3+}$ | | | | | | | | | |
| | | In-Vehicle Travel Time $\Delta IVTT_{3+}$ | | | | | | | | | |
| | 2 Person Carpool | Promotion and Matching Incentives 0,1 | | | | | | | | | |
| | | Out-of-Pocket Travel Cost $\Delta OPTC_2$ ¢ | | | | | | | | | |
| | | Out-of-Vehicle Travel Time $\Delta OVTT_2$ min. | | | | | | | | | |
| | | In-Vehicle Travel Time $\Delta IVTT_2$ min. | | | | | | | | | |
| Average Size of 3+ Person Carpools | | | | | | | | | | | |
| Base Carpool-Size Shares | 3+ Person | | | | | | | | | | |
| | 2 Person | | | | | | | | | | |
| Population Subgroup | | | | | | | | | | | |

## III. ESTIMATION OF REVISED WORK-TRIP MODAL SHARES

POLICY: ____________________

SUBGROUP: ____________________

### 1. CHANGE IN UTILITY FOR EACH MODE

**Drive Alone**

$\Delta$UTILITY = -.015 × $\Delta IVTT_{da}$ = ____

+ -.16 ÷ Trip Length × $\Delta OVTT_{da}$ = ____

+ -29.0 ÷ Income × $\Delta OPTC_{da}$ = ____

TOTAL CHANGE ____

**Shared Ride**

$\Delta$UTILITY = -.015 × $\Delta IVTT_{sr}$ = ____

+ -.16 ÷ Trip Length × $\Delta OVTT_{sr}$ = ____

+ -29.0 ÷ Income × $\Delta OPTC_{sr}$ ÷ Average Carpool Size = ____

+ .29 × Incentives = ____

TOTAL CHANGE ____

**Transit**

$\Delta$UTILITY = -.015 × $IVTT_t$ = ____

+ -.16 ÷ Trip Length × $OVTT_t$ = ____

+ -29.0 ÷ Income × $OPTC_t$ = ____

TOTAL CHANGE ____

### 2. REVISED MODAL SHARE

| | Base Modal Share | | $\Delta$Utility | | | | Total | | Revised Share |
|---|---|---|---|---|---|---|---|---|---|
| Drive Alone = | | × EXP | | = | | ÷ | | = | |
| Shared Ride = | | × EXP | | = | | ÷ | | = | |
| Transit = | | × EXP | | = | | ÷ | | = | |
| Vanpool = | | × EXP | | = | | ÷ | | = | |
| Other = | | × | 1.0 | = | | ÷ | | = | |
| | | | Total | = | | | | | |

## III-A. ESTIMATION OF CHANGES IN CARPOOL SIZE

POLICY: ______________________
SUBGROUP: ____________________

### 1. CHANGE IN UTILITY FOR EACH CARPOOL SIZE

**2 Person Carpool**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ΔUTILITY = | −.015 | X | | | $\Delta IVTT_2$ | | | = | |
| + | −.16 | ÷ | Trip Length | X | $\Delta OVTT_2$ | | | = | |
| + | −29.0 | ÷ | Income | X | $\Delta OPTC_2$ | ÷ | 2 Person Carpool Size 2.0 | = | |
| | + | .29 | | X | Incentives | | | = | |

TOTAL CHANGE

**3+ Person Carpool**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ΔUTILITY = | −.015 | X | | | $\Delta IVTT_3$ | | | = | |
| + | −.16 | ÷ | Trip Length | X | $\Delta OVTT_3$ | | | = | |
| + | −29.0 | ÷ | Income | X | $\Delta OPTC_3$ | ÷ | Average 3+ Carpool Size | = | |
| | + | .29 | | X | Incentives | | | = | |

TOTAL CHANGE

### 2. REVISED CARPOOL-SIZE SHARES

| | Base Share | | ΔUtility | | | | Total Share | | Revised Share |
|---|---|---|---|---|---|---|---|---|---|
| 2 Person | | X EXP | | = | | ÷ | | = | |
| 3+ Person | | X EXP | | = | | ÷ | | = | |

Total Share =

### 3. REVISED CHANGES IN SHARED RIDE LEVEL-OF-SERVICE (LOS)

| | Revised 2 Person Share | | 2 Person ΔLOS | | Revised 3+ Person Share | | 3+ Person ΔLOS | | Shared Ride ΔLOS |
|---|---|---|---|---|---|---|---|---|---|
| ΔIVTT | | X | | + | | X | | = | |
| ΔOVTT | | X | | + | | X | | = | |
| ΔOPTC | | X | | + | | X | | = | |
| Incentives | | X | | + | | X | | = | |

### 4. REVISED AVERAGE CARPOOL SIZE

| | Revised 2 Person Share | | 2 Person Carpool Size | | Revised 3+ Person Share | | Average 3+ Carpool Size | | Revised Average Carpool Size |
|---|---|---|---|---|---|---|---|---|---|
| 1.0 ÷ (( | | ÷ | 2.0 | ) + ( | | ÷ | | )) = | |

## IV. ESTIMATION OF CHANGES IN VMT

POLICY ______________________

SUBGROUP ______________________

### 1. REVISED HOUSEHOLD WORK TRIP VMT

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Revised Shared Ride Modal Share | | Revised Average Carpool Size | | Revised Drive Alone Modal Share | | Revised Autos Used Per Worker | | | | |
| | | ☐ | ÷ | ☐ | + | ☐ | = | ☐ | | | | |
| | | Revised Autos Used per Worker | | No. of Workers per Household | | Work Trip Length | | | | | | Auto VMT |
| | | ☐ | x | ☐ | x | ☐ | x | 2.0 | | | = | ☐ |
| Revised Vanpool Modal Share | | Average Vanpool Occupancy | | No. of Workers per Household | | Work Trip Length | | Vanpool Circuity Factor | | | | Vanpool VMT |
| ☐ | ÷ | ☐ | x | ☐ | x | ☐ | x | ☐ | x | 2.0 | = | ☐ |

Total Revised Household Work VMT ☐

### 2. CHANGE IN HOUSEHOLD WORK TRIP VMT

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Revised Household Work-Trip VMT | | Base Work Trip VMT | | Change in Work Trip VMT | | Base Work Trip VMT | | | | % Change in Work Trip VMT |
| ☐ | − | ☐ | = | ☐ | ÷ | ☐ | x | 100 | = | ☐ |

### 3. REVISED HOUSEHOLD NON-WORK TRIP VMT

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Base Autos Used per Worker | | Revised Autos Used per Worker | | No. of Workers per Household | | Change in Autos Remaining per Household |
| | { | ☐ | − | ☐ | }x | ☐ | = | ☐ |
| | Change in Autos Remaining per Household | | | | | Base Non-Work VMT | | Revised Non-Work VMT |
| { | ☐ | x | .08 | + | 1.0 }x | ☐ | = | ☐ |

### 4. CHANGE IN TOTAL HOUSEHOLD VMT FROM BASE

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Revised Work Trip VMT | | Revised Non-Work VMT | | Revised Total VMT | | | |
| | ☐ | + | ☐ | = | ☐ | | | |
| | | | | | Base Total VMT | | | |
| | | | | − | ☐ | | | |
| | | | | | | | | % Change in Total VMT |
| Change in Total VMT | | | | | ☐ | ÷ ☐ | x 100 | = ☐ |

## V. SUMMARY OF CHANGES IN VMT

**POLICY:** ____________________

| Population Subgroup | AVERAGE HOUSEHOLD VMT | | | |
|---|---|---|---|---|
| | Work Trip VMT | | Total VMT | |
| | Base | Δ | Base | Δ |
| | | | | |
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X

| Subgroup Fraction of Total Pop. |
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| NORMALIZED HOUSEHOLD VMT | | | |
|---|---|---|---|
| Work Trip VMT | | Total VMT | |
| Base | Δ | Base | Δ |
| | | | |
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AVERAGE $= \sum_{\text{Subgroup}} =$

| | | | |
|---|---|---|---|
| | | | |

| Percent Change in VMT | |
|---|---|
| Work | Total |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |

| | Average ΔVMT | | Average VMT | | | | % ΔVMT |
|---|---|---|---|---|---|---|---|
| Work Trip : | | ÷ | | x | 100 | = | |
| Total : | | ÷ | | x | 100 | = | |

## V-A. SUMMARY OF CHANGES IN MODAL SHARES

POLICY ______________________

| Population Subgroup | AVERAGE MODAL SHARE | | | | | | | | | | Fraction of Total Pop. | NORMALIZED MODAL SHARE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Drive Alone | | Shared Ride | | Transit | | Other | | Vanpooling | | | Drive Alone | | Shared Ride | | Transit | | Other | | Vanpooling | |
| | B* | R* | B | R | B | R | B | R | B | R | | B | R | B | R | B | R | B | R | B | R |
| | | | | | | | | | | | | | | | | | | | | | |
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| | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | AVERAGE $= \sum_{\text{Subgroup}} =$ | | | | | | | | | | |

* B = Base
R = Revised

# APPENDIX B

## Worksheets for the Manual Synthetic Mode Choice Method

The pages which follow consist of copies of the worksheets originally included in Ref. (48), for analyzing the impacts of transportation measures on work mode choice. The use of these worksheets is also discussed in Section 2.1.1.b.

The travel demand model incorporated in these worksheets was developed as part of a project for the U.S. Department of Transportation using household-level socioeconomic and travel information from the 1968 Washington, D.C. Council of Governments' home interview survey (5). It is a multinomial logit model which predicts mode shares for three modes: drive alone, shared ride, and transit.

The definitions of variables used in this model and its coefficients are presented in Figure 5.2 and Table 5.2 in this report. Note that the cost coefficients have been estimated in 1968 dollars (or cents). These coefficients should be adjusted for use with data for later years if the relative inflation rates for income and transportation costs are known.

## B.1 SYNTHETIC MODE CHOICE MODEL - DRIVE ALONE UTILITY

Base Alternative

Revised Alternative

Policy: ____________________

**OVTT Term**

| | | | | | | |
|---|---|---|---|---|---|---|
| | | $OVTT_{DA}$ | | DIST | | + |
| -.1599 | * | ☐ | ÷ | ☐ | = | ☐ |

**IVTT term**

| | | | | |
|---|---|---|---|---|
| | | $IVTT_{DA}$ | | + |
| -.01535 | * | ☐ | = | ☐ |

**COST term**

| | | | | | | |
|---|---|---|---|---|---|---|
| | | $OPTC_{DA}$ | | INCOME | | + |
| -28.84 | * | ☐ | ÷ | ☐ | = | ☐ |

**Constant terms**

| | | | | |
|---|---|---|---|---|
| | | | | + |
| -3.244 | | | = | ☐ |
| | | CBD | | + |
| -.8540 | * | ☐ | = | ☐ |

**Socioeconomic terms**

| | | | | |
|---|---|---|---|---|
| | | AALD | | + |
| 3.987 | * | ☐ | = | ☐ |
| | | BW | | + |
| .8897 | * | ☐ | = | ☐ |
| | | DINC | | + |
| $7.06 \times 10^{-5}$ | * | ☐ | = | ☐ |

$U_{DA}$ = total DA utility = ☐

## B.2 SYNTHETIC MODE CHOICE MODEL - SHARED-RIDE UTILITY

Base Alternative

Revised Alternative

Policy:____________________

### OVTT Term

| | | | | | | |
|---|---|---|---|---|---|---|
| | | $OVTT_{SR}$ | | DIST | | + |
| -.1599 | * | | ÷ | | = | |

### IVTT term

| | | | | |
|---|---|---|---|---|
| | | $IVTT_{SR}$ | | + |
| -.01535 | * | | = | |

### COST term

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | $OPTC_{DA}$ | | INCOME | Shared Ride Occupancy | | + |
| -28.84 | * | | ÷ | | 2.3 | = | |

### Constant terms

| | | | | |
|---|---|---|---|---|
| -2.242 | | | = | |
| | | CBD | | + |
| -.4036 | * | | = | |

### Socioeconomic terms

| | | | | | | |
|---|---|---|---|---|---|---|
| | | AALD | | | | + |
| 1.619 | * | | | | = | |
| | | GW | | | | + |
| .2867 | * | | | | = | |
| | | DINC | | | | + |
| $7.06x10^{-5}$ | * | | | | = | |
| | | WRK | | | | + |
| .0983 | * | | | | = | |
| | | EDEN | | DIST | | + |
| $6.53x10^{-4}$ | * | | * | | = | |

$U_{SR}$ = total SR utility = ☐

## B.3 SYNTHETIC MODE CHOICE MODEL - TRANSIT UTILITY

Base Alternative

Revised Alternative

Policy:____________________

**OVTT Term**

$$\boxed{-.1599} \; * \; \overset{\text{OVTT}_T}{\boxed{\qquad}} \; \div \; \overset{\text{DIST}}{\boxed{\qquad}} \qquad = \; \overset{+}{\boxed{\qquad}}$$

**IVTT term**

$$\boxed{-.01535} \; * \; \overset{\text{IVTT}_T}{\boxed{\qquad}} \qquad = \; \overset{+}{\boxed{\qquad}}$$

**COST term**

$$\boxed{-28.84} \; * \; \overset{\text{OPTC}_T}{\boxed{\qquad}} \; \div \; \overset{\text{INCOME}}{\boxed{\qquad}} \qquad = \; \overset{+}{\boxed{\qquad}}$$

---

$U_T$ = total T utility $= \boxed{\qquad}$

## B.4 SYNTHETIC MODE CHOICE MODEL - MODE SHARES

Base Alternative

Revised Alternative

Policy:

$U_{DA}$ (B.1)[1]

Exp =

+

$U_{SR}$ (B.2)

Exp =

+

$U_T$ (B.3)

Exp =

---

Exp $U_k$ =

### Drive Alone Mode Share

Exp ($U_{DA}$) Exp ($U_k$)

$P_{DA}$ = ÷ =

### Shared-Ride Mode Share

Exp ($U_{SR}$) Exp ($U_k$)

$P_{SR}$ = ÷ =

### Transit Mode Share

Exp ($U_T$) Exp ($U_k$)

$P_T$ = ÷ =

---

[1] The characters enclosed in parentheses identify source worksheets.

# APPENDIX C

## INCREMENTAL WORK TRIP MODE CHOICE PROGRAM DOCUMENTATION

This appendix consists of two sections which together contain a complete description of the program 3MODE(VAN)-AGG. The first section, User Documentation, is directed to the analyst who will establish the analysis procedures and to the technician who will actually complete the analyses. The second section is the detailed documentation which lists the program and other technical information. This will be valuable for anyone who wishes to write a new program or modify this one.

The user documentation consists of the following nine sections:

- Purpose
- Calculator
- Keywords
- Symbols and Codes
- General Description
- Data Requirements
- Procedure
- Comments
- Example

The person who sets up the analysis process should pay particular attention to the General Description (which includes limitations and capabilities), Data Requirements, and the first two worksheets (base data and changes in level of service) under Procedure. If a user-supplied model is desired in place of the default model, the last two sections under Comments (User-Supplied Coefficients and User-Supplied Model Specification and Coefficients) must be studied. The person who actually performs an analysis with this program will need the worksheets in the Procedure section and the first part of Comments - Use of the Default

Coefficients. Figure C.1 illustrates the steps of an analysis using this calculator program.

The detailed documentation consists of eight sections:

- Detailed Logic
- Registers
- Symbols and Codes
- Flow Chart
- Labels
- Flags
- Card Formats
- Program

These sections list the actual program and describe information which is of interest to a calculator programmer, but is not needed for the use of the program. To revise this program, it will be necessary to refer to the list of program steps and, of course, to understand the programming instructions for whichever calculator is being used.

Program 3MODE(VAN)-AGG is an example of a typical program which can be written for the calculator. It is a prototype of what can easily be done to adapt lengthy manual analysis techniques to calculator techniques.

## FIGURE C.1

### Analysis Steps

- Determine Policies and Policy Packages for Analysis
- For each policy or policy package:
    - Determine market segmentation
    - For each market segment:
        - Determine number of workers
        - Determine average round trip distance
        - Determine base mode shares
        - Determine changes in level of service
        - Determine occupancies - carpool and vanpool
        - Determine circuity factor - vanpool
        - Run program
    - Record aggregated results (over all market segments)

# I. USERS' DOCUMENTATION: Incremental Work Trip Mode Choice Model (3MODE-VAN-AGG)

## A. PURPOSE

This program is designed to revise work trip modal shares for three modes (drive alone, shared ride or carpool, and transit) with an option for including vanpool as a new or revised mode. In the default version of the model, revised mode shares reflect changes in any or all of the following level-of-service variables:

- in-vehicle travel time
- out-of-vehicle travel time
- out-of-pocket travel cost
- carpool/vanpool incentives

In addition to revised modal shares, the program produces data on revised modal volumes and vehicle miles of travel. Emissions impacts of policies under analysis can then be determined by using these outputs as inputs to an emissions calculation procedure such as that described in Appendix D.

The program can be used to analyze an unlimited number of market segments for any policy and of aggregating the modal volumes and (non-transit) vehicle miles of travel over all the segments.

The program has been written to provide as a default the specification of a multinomial logit work mode choice model estimated from 1968 Washington, D.C. area data.[1] This specification requires only four coefficients in the incremental form, but capacity for five coefficients per mode (a total of fifteen) has been provided. This was done for ease in revision of the default model or substitution of a user-specified model, if desired.

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[1] See below for the specification of this model, which is documented fully in Cambridge Systematics, Inc., "A Behavioral Model of Automobile Ownership and Mode of Travel", U.S. Department of Transportation, Office of the Secretary, Federal Highway Administration, 1974.

## B. CALCULATOR

TI59; with PC100A printer optional

## C. KEYWORDS

Mode choice, incremental logit model, aggregation, vehicle occupancy, vanpools

## D. GENERAL DESCRIPTION

### 1. Main Program

This program is capable of analyzing an unlimited number of market segments and of aggregating the modal volumes and non-transit VMT results over all the segments. Each market segment can have up to five modes which are defined as the user wishes with two restrictions.*

- The fourth mode (vanpool, if default coefficients are used) uses the same coefficients as the second mode (carpool).
- There is no analysis of the fifth mode ("other"). Level of service for "other" modes is expected to remain constant and the share is included so that the sum of modal shares always equals one.

Each of the first three modes can have up to five coefficients (unique to the mode, if desired). Extra coefficient storage registers may be left equal to zero (to remain unused) or used as constants to modify the effects of the level-of-service coefficients.**

The program can handle three different types of vanpool mode share changes:

- base share equal to zero and new share equal to zero;
- base share equal to zero and new share greater than zero;
- base share greater than zero and new share greater than zero.

---

* Use of the default coefficients suggests use of the default modes: drive alone, carpool, transit, vanpool, and other (walk, cycle, taxi).

** This modification of constants is typically done in transferring entire models, and is not often used in pivot point applications. See Ben-Akiva, Moshe and Terry Atherton, Transferability and Updating of Disaggregate Travel Demand Models, Transportation Research Board, 1976.

In the first and third cases, the actual base vanpool share is entered by the user and the new shares are determined from the changes in modal levels of service. In the second case, the vanpool subroutine described below is used to create a base share on which to pivot.

The calculation of estimated changes in transportation modal shares incorporated into the program is based on the incremental form of the multinomial logit model.* Based on probabilistic choice theory, this form is used to pivot about an existing situation. The approach predicts _revised_ travel behavior based on _existing_ travel behavior and _changes_ in level of service rather than employing a full transportation demand model system to recalculate modal shares based on detailed household, zonal, and level-of-service data. By employing a "pivot-point" approach, data requirements are greatly reduced: no knowledge of detailed socioeconomic and level-of-service data for each household or zone is required. Only existing estimates of modal shares (probabilities) and proposed changes in level of service are necessary.

The logit model predicts the probability that a behavioral unit will make choice "i" from the set of alternatives "A" and is expressed in the following exponential form:

---

* Background on the theory and derivation of this model is presented in: Richard, Martin G., and Moshe E. Ben-Akiva, _A Disaggregate Travel Demand Model_ (Westmead, Farnborough, Hants, England: Saxon House/ Lexington Books) 1975.

$$P(i:A) = \frac{e^{U_i}}{\sum_{m \epsilon A} e^{U_m}} \qquad (C-1)$$

where:

m,i = travel mode alternatives

A = the set of possible choices

P(i:A) = the probability of choosing alternative i out of the set of the available alternatives A

$U_m$, $U_i$ = the utility of alternatives m and i

This particular model form exhibits many favorable properties which make it desirable to use. First, the exponential form is in agreement with consumer behavior theory (i.e., if an alternative begins with a choice probability of 0.5 or greater, the initial response to an increment of utility improvement is greater than the response to a later increment of utility improvment of the same magnitude). Second, the probabilities necessarily sum to one as they should. Third, the curve of P(i:A) versus $U_i$ has the general shape of the curve of "diminishing returns" at both ends. This reflects known travel behavior nicely; i.e., no matter how good (or bad) a service is, all of the ridership is never captured (or lost), and ridership is most susceptible to diversion to some other alternative in the highly competitive middle range. Fourth, the logit model is capable of extension to any number of travel alternatives. Finally, the logit form is mathematically tractable, leading to simplicity in calibration, transformation, and application.

Any change in transportation will result in a change in the level of service $X_{ij}$, and therefore a change in the utility function as expressed by the weighted sum of transportation and socioeconomic variables (or $U_i = \sum_j \theta_{ij} X_{ij}$). The revised probability resulting from changes in modal utilities is given by:

$$P'(i:A) = \frac{e^{U_i + \Delta U_i}}{\sum_{m \in A} e^{U_m + \Delta U_m}} \qquad \text{(C-2)}$$

where:

$\Delta U_i$ = the change in utility for alternative i

= $\sum_j \theta_{ij} \Delta X_{ij}$

$\theta_{ij}$ = a calibrated model coefficient

$\Delta X_{ij}$ = a change in an independent variable

$P'(i:A)$ = the predicted probability of choosing alternative i when $U_i$ changes by $\Delta U_i$

Equation (C-2) can be represented by:

$$P'(i:A) = \frac{e^{U_i} \cdot e^{\Delta U_i}}{\sum_{m \in A} e^{U_m} \cdot e^{\Delta U_m}} \qquad \text{(C-3)}$$

Dividing both the numerator and denominator of (C-3) by $\sum_{m \in A} e^{U_m}$ yields:

$$P'(i:A) = \frac{[e^{U_i} / \sum_{m\epsilon A} e^{U_m}] \cdot e^{\Delta U_i}}{\sum_{m\epsilon A} [e^{U_m} / \sum_{m\epsilon A} e^{U_m}] \quad e^{\Delta U_m}} \qquad \text{(C-4)}$$

which can be written as:

$$P'(i:A) = \frac{p(i:A) \cdot e^{\Delta U_i}}{\sum_{m\epsilon A} P(m:A) e^{\Delta U_m}} \qquad \text{(C-5)}$$

Note that whenever p(i:A) equals zero, P'(i:A) will equal zero regardless of the change in utility or probabilities of other modes.

To be completed, the probabilities obtained from this equation must be expanded into an aggregate forecast of travel behavior. A straightforward and simple approach is to use average values of existing choice probabilities and of changes in level of service for a given population subgroup. The incremental model form expressed in the program then simply replaces P(i:A), the probability of an individual choosing alternative i with the base modal share for that alternative, and $X_{ij}$, the change in transportation level of service for an individual, with the average change in that variable for all trips. Thus, aggregate or population subgroup modal shares become the basic units for which transportation-related impacts are predicted.

The travel demand modal choice model incorporated as a default into the program is of the logit type described above. It was developed as part of a project for the U.S. Department of Transportation.[1] The calibrated model predicts the probability of a person driving alone, sharing a ride, or using transit for the home-to-work trip. Using this definition of alternative modes, all travellers who are part of a carpool or vanpool are treated as shared riders, regardless of who actually drives the vehicle; i.e., drivers with passengers, as well as passengers, are classified as shared riders.

The model was calibrated by the method of maximum likelihood estimation[2] using household-level socioeconomic and travel information from the 1968 Washington, DC, Council of Governments home interview survey. The model specification, coefficients, and statistical properties are shown in Table C.1. All important coefficients are significant with low standard errors (and correspondingly high "t" statistics). The variables used in specifying the model can be classifeid into three types: socioeconomic (e.g., household income, automobile ownership, number of workers); land use and locational (e.g., distance, workplace, employment

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[1] Cambridge Systematics, Inc., A Behavioral Model of Automobile Ownership and Mode of Travel, U.S. Department of Transportation, Office of the Secretary, and the Federal Highway Administration, Washington DC 1974.

[2] "Maximum likelihood estimation" is a technique for curvefitting or calibration, similar to least-squares or regression techniques but more sophisticated and compatible with the non-linear logit form.

## TABLE C.1

## Washington Work Mode Choice Model

| $X_i$, $S_t$ Variable | Definition | Drive Alone | Shared Ride | Transit | Standard Error | "t" Statistic |
|---|---|---|---|---|---|---|
| $D_d$ | Drive alone constant | -3.24 | | | .473 | -6.86 |
| $D_s$ | Shared ride constant | | -2.24 | | .401 | -5.60 |
| OCTC/INC | Out-of-pocket travel cost divided by income (round trip) | -28.8 | -28.8 | -28.8 | 12.7 | -2.26 |
| IVTT | In-vehicle travel time (round trip) | -.0154 | -.0154 | -.0154 | .0057 | -2.67 |
| OVTT/DIST | Out-of-vehicle travel time divided by distance (round trip) | -.320 | -.320 | -.320 | .078 | -4.08 |
| $AALD_d$ | Auto availability (drive alone only) | 3.99 | | | .395 | 10.08 |
| $AALD_s$ | Auto availability (shared ride only) | | 1.62 | | .305 | 5.31 |
| $BW_d$ | Breadwinner (drive alone only) | .890 | | | .186 | 4.79 |
| $GW_s$ | Government worker (shared ride only) | | .287 | | .161 | 1.78 |
| $DCITY_d$ | CBD workplace (drive alone only) | -.854 | | | .311 | -2.75 |
| $DCITY_s$ | CBD workplace (shared ride only) | | -.404 | | .298 | -1.36 |
| $DINC_{d,s}$ | Disposable income (drive alone & shared ride only) | .000071 | .000071 | | .00002 | 3.46 |
| $NWORK_s$ | No. of workers (shared ride only) | | .0983 | | .095 | 1.03 |
| $DTECA_s$ | Employment density (shared ride only) | | .00065 | | .00049 | 1.34 |

density); and transportation level-of-service (e.g., out-of-pocket travel cost, in-vehicle travel time, out-of-vehicle travel time).

For use in the program, the calibrated model has been expanded in two ways:

- The shared ride mode has been further subdivided into two modes, carpool and vanpool, depending on the type of vehicle used. Both of these modes have utility functions with the same structure, equal to that calibrated for the shared-ride mode.
- A fifth mode, "other", is included to represent all modes of travel not included in the four other modes. The utility of this mode is never allowed to change. It is included so that all base mode shares sum to one.

When revised modal shares have been determined by the program, modal volumes and VMT are determined. The equation for modal volume is:

$$VOL_m = S_m * Pop \qquad (C-6)$$

where:

$Vol_m$ = Volume of mode m

$S_m$ = Share of mode m

$Pop$ = Number of workers in the market segment

The equation for VMT for one market segment is:

$$VMT_{TOT} = VOL_{DA} + \frac{VOL_{CP}}{OCC_{CP}} + \frac{VOL_{VP} * CIRC}{OCC_{VP}}) * DIST \qquad (C-7)$$

where:

$VOL_{DA}$ = Drive alone volume
$VOL_{CP}$ = Carpool volume
$VOL_{VP}$ = Vanpool volume
$OCC_{CP}$ = Carpool occupancy
$OCC_{VP}$ = Vanpool occupancy
$CIRC$ = Vanpool circuity factor
$DIST$ = Round-trip distance

## 2. Vanpool Subroutine

The purpose of this subroutine is to "create" a non-zero base on which to pivot the vanpool mode share.[1] Adjustments are made to the base shares in other modes so that the adjusted base mode shares (including vanpool) sum to one. If there is a non-zero base vanpool share, it can be used directly in the pivot point program without employing this subroutine. The program equations are:

$$S^a_{DA} = S_{DA} - .5 * S_{VP}(1 - S_T) \qquad \text{(C-8)}$$

$$S^a_{CP} = S_{CP} - .5 * S_{VP}(1 - S_T) \qquad \text{(C-9)}$$

$$S^a_T = S_T(1 - S_{VP}) \qquad \text{(C-10)}$$

where:

$S_{DA}$ = Base drive alone share

$S^a_{DA}$ = Adjusted drive alone share

$S_{CP}$ = Base shared ride share

$S^a_{CP}$ = Adjusted shared ride share

$S_T$ = Base transit share

$S^a_T$ = Adjusted transit share

$S_{VP}$ = Specified base vanpool share

These incorporate the assumptions that:

- the proportion of the new vanpool mode share made up of commuters previously using transit is equal to the existing transit modal share, and
- an equal number of drive-alone and carpool commuters are attracted to vanpools.

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[1] A zero base share will always give a zero revised share. An assumption must be made about an adjusted vanpool share if the revised share is expected to be non-zero.

For example, if the existing modal share of transit were 15 percent, 15 percent of the new vanpool modal share would be from transit, and the transit modal share would be reduced accordingly. Note that because the carpool modal share is generally less than the drive-alone share, the contribution of carpool as a percentage of its modal share will be greater than the corresponding percentage for drive-alone. Because "other" modes, such as walk, taxi, bicycle, etc., are assumed to be unavailable to the population subgroup with vanpooling available, these modes remain unaffected by the introduction of vanpooling. This is consistent with the fact that vanpooling is usually only offered to and attractive for employees with long commuting distances and poor access to transit.

### 3. Carpool Subroutine

This subroutine is used in the analysis of any policy which treats carpools differentially based on the number of passengers in the vehicle. Only two classes of carpools can be handled; normally, if the distinction is not between two and three-or-more (3+) person carpools, it will be between two- and three- (2/3) person carpools and four-or-more (4+) person carpools.

When changes in level of service attributable to the policy under analysis have been determined for the two classes of carpools, they are entered in the subroutine along with the average vehicle occupancy and share of carpool trips for each class. The subroutine is an incremental logit model which treats carpool as the only available mode and computes revised carpool shares, average changes in level of service for all carpools, and a revised average vehicle occupancy for all carpools. The series of equations for this are:

$$S'_{CP1} = \frac{S_{CP1} \cdot e^{\Delta U_{CP1}}}{\sum_i S_{CPi} \cdot e^{\Delta U_{CPi}}} \qquad \text{(C-11)}$$

$$S'_{CP2} = \frac{S_{CP2} \cdot e^{\Delta U_{CP2}}}{\sum_i S_{CPi} \cdot e^{\Delta U_{CPi}}} \qquad \text{(C-12)}$$

$$\Delta LOS_{CP} = S'_{CP1} \cdot \Delta LOS_{CP1} + S'_{CP2} \cdot \Delta LOS_{CP2} \qquad \text{(C-13)}$$

$$OCC_{CP} = 1/[(S'_{CP1}/OCC_{CP1}) + (S'_{CP2}/OCC_{CP2})] \qquad \text{(C-14)}$$

where:

$S_{CPi}$ = base carpool share for class i

$S'_{CPi}$ = revised carpool share for class i

$\Delta U_{CPi}$ = change in utility for carpool class i

$LOS_{CPi}$ = level of service for carpool class i

$LOS_{CP}$ = level of service averaged for all carpools

$OCC_{CPi}$ = average occupancy of carpools in class i

$OCC_{CP}$ = average occupancy of all carpools

The output data from this subroutine is used as input for the carpool mode in the main program.

## E. SYMBOLS AND CODES

Modes:

DA = Drive Alone

SR = Shared Ride

CP = Carpool

CP1 = Carpool class 1
CP2 = Carpool class 2

VP = Vanpool

T = Transit

O = Other

TOT = All modes

Variables:

$IVTT_m$ = In-vehicle travel time for mode m

$OVTT_m$ = Out-of-vehicle travel time for mode m

$OPTC_m$ = Out-of-pocket travel cost for mode m

INCENT = Incentives for the carpool and vanpool modes only

DIST = Round-trip distance

Y = Average household income for a market segment

$OCC_m$ = Average vehicle occupancy for mode m

CIRC = Vanpool circuity factor

POP = Market segment population

$U_m$ = Utility of mode m

$VOL_m$, $VOL'_m$ = Base and new volume of mode m

$VMT_m$, $VMT'_m$ = Base and new vehicle-miles of travel for mode m

$S_m$, $S^a_m$, $S'_m$ = Base, adjusted, and new share of mode m

A/W, A/W' = Base and new autos per worker

$\Sigma x$ = Variable x, summed over all market segments

Other:

$\theta n_m$ = Coefficient of variable n for mode m

$\Delta n_m$ = Change in variable n for mode m

## F. DATA REQUIREMENTS

### 1. Main Program

For each market segment:

- round trip distance in miles
- household average annual income in miles
- average carpool occupancy
- number of workers in the market segment
- average vanpool occupancy
- vanpool circuity factor - the ratio of vanpool travel distance to drive-alone travel distance. This ratio is normally greater than one reflecting increases for the purpose of picking up passengers.
- base mode shares:
  - drive alone
  - carpool
  - transit
  - vanpool
  - other
- round trip changes in level of service for each mode:
  - in-vehicle travel time
  - out-of-vehicle travel time
  - out-of-pocket travel cost
  - incentives (carpool and vanpool only)

### 2. Additional Data for Vanpool Subroutine

- specified base mode share for vanpool for each market segment

## 3. Additional Data for Carpool Subroutines

For each market segment:

- average occupancy for carpool classes 1 and 2
- share of total carpool volume in classes 1 and 2
- changes in level of service for each segment:
  - in-vehicle travel time
  - out-of-vehicle travel time
  - out-of-pocket travel cost
  - incentives

These data items can be organized and documented on the three worksheets which follow this section:

C-1 Base Data

C-2 Changes in Transportation Level of Service

C-3 Changes in Transportation Level of Service by Carpool Size

**WORKSHEET C-1**

**BASE DATA**

**POLICY:** ____________________

| Population Subgroup | Average round Trip Length (mi) | Annual Household Income ($) | Average Carpool Size | Population | Average Vanpool Size | Vanpool Circuity Factor | Base Work Trip Modal Shares | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Drive Alone | Carpool | Transit | Vanpool | Other |
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**WORKSHEET C-2**

**POLICY:** ____________________

## CHANGES IN TRANSPORTATION LEVEL OF SERVICE

**(all data represent round trips)**

| Population Subgroup | Drive Alone | | | Carpool | | | | Transit | | | Vanpool | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In-Vehicle Travel Time $\Delta IVTT_{da}$ (min.) | Out-of-Vehicle Travel Time $\Delta OVTT_{da}$ (min.) | Out-of-Pocket Travel Cost $\Delta OPTC_{da}$ (¢) | In-Vehicle Travel Time $\Delta IVTT_{cp}$ (min.) | Out-of-Vehicle Travel Time $\Delta OVTT_{cp}$ (min.) | Out-of-Pocket Travel Cost $\Delta OPTC_{cp}$ (¢) | Carpool Promotion & Matching Incentives (0,1) | In-Vehicle Travel Time $\Delta IVTT_{t}$ (min.) | Out-of-Vehicle Travel Time $\Delta OVTT_{t}$ (min.) | Out-of-Pocket Travel Cost $\Delta OPTC_{t}$ (¢) | In-Vehicle Travel Time $\Delta IVTT_{vp}$ (min.) | Out-of-Vehicle Travel Time $\Delta OVTT_{vp}$ (min.) | Out-of-Pocket Travel Cost $\Delta OPTC_{vp}$ (¢) | Vanpool Promotion & Matching Incentives (0,1) |
| | | | | | | | | | | | | | | |
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**WORKSHEET C-3**

**CHANGES IN TRANSPORTATION LEVEL OF SERVICE BY CARPOOL SIZE**

**POLICY:** ____________________

Class 1= ____ person carpools

Class 2= ____ person carpools

| Population Subgroup | Base Shares by Carpool Size Segmen | | Average Size of Carpool by Segment | | Changes in Transportation Level of Service (Round Trip) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Class 1 | | | | Class 2 | | | |
| | Class 1 | Class 2 | Class 1 | Class 2 | In-Vehicle Travel Time $\Delta IVTT_{CP1}$ (min.) | Out-of-Vehicle Travel Time $\Delta OVTT_{CP1}$ (min.) | Out-of-Pocket Travel Cost $\Delta OPTC_{CP1}$ (¢) | Promotion and Matching $Incentives_{CP1}$ (0,1) | In-Vehicle Travel Time $\Delta IVTT_{CP2}$ (min.) | Out-of-Vehicle Travel Time $\Delta OVTT_{CP2}$ (min.) | Out-of-Pocket Travel Cost $\Delta OPTC_{CP2}$ (¢) | Promotion and Matching $Incentives_{CP2}$ (0,1) |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
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| | | | | | | | | | | | | |

## G. PROCEDURE

Travellers who are affected by the policy under consideration should be grouped in market segments which are internally homogeneous. (See Section 5.3.) The classification criteria generally appropriate are: modal availability, socioeconomic characteristics, and trip orientation. The classification employed will depend on the nature of the air quality policy and the groups which are affected.

When market segments have been classified and all necessary data compiled, the program should be run using the procedure outlined on the worksheets which follow. These worksheets include:

| | |
|---|---|
| C-4 | Program Steps |
| C-5 | Carpool Subroutine |
| C-6 | Results by Market Segment |

The next section (H) contains supplementary discussion for selected steps.

## WORKSHEET C-4 PROGRAM STEPS

639.39
(3MODE(VAN)-AGG-2(B)/7900110/ESE)

### USER INSTRUCTIONS

| STEP | PROCEDURE | ENTER | PRESS | | | DISPLAY |
|---|---|---|---|---|---|---|
| 1 | Read card(s) - partitioning is 639.39 | | | | | |
| 2 | Initialize Storage Registers and store default Coefficients | | A | | | .29 |
| | If default coefficients are used, skip to STEP 4 | | | | | |
| 3 | OPTIONAL - Enter user-supplied coefficients | | | | | |
| 3a | coefficient of IVTT-DA mode | $\theta_1$DA = ____ | STO | 00 | | |
| 3b | coefficient of OVTT/DIST-DA mode | $\theta_2$DA = ____ | STO | 01 | | |
| 3c | coefficient of OPTC/Y-DA mode | $\theta_3$DA = ____ | STO | 02 | | |
| 3d | coefficient 4-DA mode | $\theta_4$DA = ____ | STO | 03 | | |
| 3e | coefficient 5-DA mode | $\theta_5$DA = ____ | STO | 04 | | |
| 3f | coefficient of IVTT-SR mode | $\theta_1$SR = ____ | STO | 05 | | |
| 3g | coefficient of OVTT/DIST-SR mode | $\theta_2$SR = ____ | STO | 06 | | |
| 3h | coefficient of OPTC/Y-SR mode | $\theta_3$SR = ____ | STO | 07 | | |
| 3i | coefficient of incentives-SR mode | $\theta_4$SR = ____ | STO | 08 | | |
| 3j | coefficient 5-SR mode | $\theta_5$SR = ____ | STO | 09 | | |
| 3k | coefficient of IVTT-T mode | $\theta_1$T = ____ | STO | 10 | | |
| 3l | coefficient of OVTT/DIST-T mode | $\theta_2$T = ____ | STO | 11 | | |
| 3m | coefficient of OPTC/Y-T mode | $\theta_3$T = ____ | STO | 12 | | |
| 3n | coefficient 4-T mode | $\theta_4$T = ____ | STO | 13 | | |
| 3o | coefficient 5-T mode | $\theta_5$T = ____ | STO | 14 | | |
| | IF A MISTAKE IS MADE, BEGIN AGAIN AT STEP 3a | | | | | |
| 4 | Enter market segment data (from worksheet II-1) | | | | | |
| 4a | round trip distance in miles $\neq 0$ | DIST= ____ | R/S | | | |
| 4b | household average annual income in \$ $\neq 0$ | Y = ____ | R/S | | | |
| | enter "1" if income is not needed for this segment. | | | | | |
| 4c | Average carpool occupancy $\neq 0$ | $OCC_{CP}$= ____ | R/S | | | |
| | Default = 2.5 | | | | | |
| 4d | Market segment population | POP = ____ | R/S | | | |

WORKSHEET C-4
(continued)
(3MODE(VAN)-AGG-2(B)/790110/ESE)

## USER INSTRUCTIONS

| STEP | PROCEDURE | ENTER | PRESS | | | DISPLAY |
|---|---|---|---|---|---|---|
| 4e | Average vanpool occupancy ≠ 0<br>default -- 10 | $OCC_{VP}$ = ___ | R/S | | | |
| 4f | Vanpool circuity factor ≠ 0<br>default -- 1.5 | CIRC = ___ | R/S | | | |
| | If a mistake is made, press $\boxed{C}$ and begin with STEP 4a | | | | | |
| | If carpool subroutine is not used, go to STEP 6 | | | | | |
| 5 | OPTIONAL - Carpool Subroutine (data from worksheet II-3) | | 2nd | C' | | 38 |
| 5a | Enter average occupancies of two classes of carpools: | | | | | |
| | 1. Average occupancy carpool class 1 | $OCC_{CP1}$= ___ | R/S | | | |
| | 2. Average occupancy carpool class 2 | $OCC_{CP2}$= ___ | R/S | | | |
| 5b | Enter level of service and mode share data | | | | | |
| | 1. ΔIVTT - carpool class 1 | Δ = ___ | R/S | | | |
| | 2. ΔOVTT - carpool class 1 | Δ = ___ | R/S | | | |
| | 3. ΔOPTC - carpool class 1 | Δ = ___ | R/S | | | |
| | 4. ΔINCENT - carpool class 1 (0/1) | Δ = ___ | R/S | | | |
| | 5. $\Delta_5$ - carpool class 1** | Δ = ___ | R/S | | | |
| | 6. carpool class 1 share as a fraction of all carpools * | $S_{CP1}$= ___ | R/S | 2nd | E' | |
| | If a mistake is made, press $\boxed{C'}$ and begin with STEP 5a | | | | | |
| | 7. ΔIVTT- carpool class 2 | Δ = ___ | R/S | | | |
| | 8. ΔOVTT - carpool class 2 | Δ = ___ | R/S | | | |
| | 9. ΔOPTC- carpool class 2 | Δ = ___ | R/S | | | |
| | 10. Δ INCENT - carpool class 2 (0/1) | Δ = ___ | R/S | | | |
| | 11. $\Delta_5$ - carpool class 2** | Δ = ___ | R/S | | | |
| | 12. carpool class 2 share as a fraction of all carpools* | $S_{CP2}$= ___ | R/S | | | |
| | If a mistake is made, press $\boxed{C'}$ and begin with STEP 5a | | | | | |

* These two values should sum to 1.0

** If default coefficients are used, these Δ's must equal zero.

WORKSHEET C-4
(continued)
(3MODE(VAN)-AGG-2(B)/790110/ESE)

### USER INSTRUCTIONS

| STEP | PROCEDURE | ENTER | PRESS | | | DISPLAY |
|---|---|---|---|---|---|---|
| 5c | carpool subroutine results: | | | | | |
| | 1. New average occupancy for all carpools | | R/S | | | *$OCC_{CP}$ = ______ |
| | 2. New carpool change in level of service (for all carpools) | | | | | |
| | Enter $\Delta$LOS for carpool class 1 | $\Delta_{CP1}$= ______ | R/S | | | |
| | Enter $\Delta$LOS for carpool class 2 | $\Delta_{CP2}$= ______ | R/S | | | $\Delta_{CP}$ = ______ |
| | To repeat for another change in level of service, press D' and repeat STEP 5c2. | | 2nd | D' | | |
| | Step 5 results can also be recorded on Worksheet II-5. | | | | | |
| | To continue with STEP 6 | | R/S | | | |
| 6 | Store modal shares for this market segment (from Worksheet II-1) | | | | | |
| 6a | Base drive-alone share as a fraction ** (i.e., .645, not 64.5) | $S_{DA}$ = ______ | R/S | | | |
| 6b | Base carpool share as a fraction ** | $S_{CP}$ = ______ | R/S | | | |
| 6c | Base transit share as a fraction ** | $S_T$ = ______ | R/S | | | |
| 6d | Base vanpool share as a fraction ** | $S_{VP}$ = ______ | R/S | | | |
| 6e | Base "other" share as a fraction ** | $S_O$ = ______ | R/S | | | |
| 6f | Base autos per worker | | R/S | | | A/W = ______ |
| | If a mistake is made, press GO TO 1/X and begin with STEP 6a. | | | | | |
| 6g | Base VMT | | R/S | | | $VMT_{TOT}$= ______ |
| | If vanpool subroutine is not used, go to STEP 8 | | | | | |
| 7 | OPTIONAL Vanpool Subroutine | | | | | |
| | If VP = 0 in 6d and the revised vanpool share ≠ 0, enter a "base" vanpool share on which to pivot. Defaults --<br>.14 for firms with $\leq$ 2000 employees<br>.06 for firms with $\geq$ 2000 employees | $S_{VP}$ = ______ | R/S | | | |
| | If a mistake is made, press B' and repeat STEP 7 | | | | | |

---

* printed but not displayed

** these five fractions must sum to 1

# WORKSHEET C-4
(continued)
(3MODE(VAN)-AGG-2(B)/790110/ESE)

## USER INSTRUCTIONS

| STEP | PROCEDURE | ENTER | PRESS | | | DISPLAY |
|---|---|---|---|---|---|---|
| 8 | Enter changes in level of service from Worksheet II-2) | | D | | | |
| | If there are NO changes in level of service, Press $\boxed{B}$ and go to STEP 10; otherwise, | | B | | | |
| | Drive Alone changes: | | | | | |
| 8a | $\Delta IVTT_{DA}$ | Δ = _____ | R/S | | | |
| 8b | $\Delta OVTT_{DA}$ | Δ = _____ | R/S | | | |
| 8c | $\Delta OPTC_{DA}$ | Δ = _____ | R/S | | | |
| 8d | $\Delta 4_{DA}$ ** | Δ = _____ | R/S | | | |
| 8e | $\Delta 5_{DA}$ ** | Δ = _____ | R/S | | | |
| | If there are no additional changes in LOS, press $\boxed{B}$ and go to STEP 10 | | B | | | |
| | Carpool changes from Step 5 or Worksheet II-5 if optional STEP 5 was used: | | | | | |
| 8f | $\Delta IVTT_{CP}$ | Δ = _____ | R/S | | | |
| 8g | $\Delta OVTT_{CP}$ | Δ = _____ | R/S | | | |
| 8h | $\Delta OPTC_{CP}$ | Δ = _____ | R/S | | | |
| 8i | $\Delta INCENT_{CP}$ * | Δ = _____ | R/S | | | |
| 8j | $\Delta 5_{CP}$ ** | Δ = _____ | R/S | | | |
| | If there are no additional changes in LOS, press $\boxed{B}$ and go to STEP 10 | | B | | | |
| | Transit changes: | | | | | |
| 8k | $\Delta IVTT_{T}$ | Δ = _____ | R/S | | | |
| 8l | $\Delta OVTT_{T}$ | Δ = _____ | R/S | | | |
| 8m | $\Delta OPTC_{T}$ | Δ = _____ | R/S | | | |
| 8n | $\Delta 4_{T}$ ** | Δ = _____ | R/S | | | |
| 8o | $\Delta 5_{T}$ ** | Δ = _____ | R/S | | | |
| | If a mistake is made, press $\boxed{\text{GO TO}}$ $\boxed{1/X}$ and begin at STEP 6a | | | | | |
| | If the vanpool share in 6d = 0 and STEP 7 was not used, GO TO STEP 10 | | | | | |
| 9 | OPTIONAL: Enter vanpool change in LOS (from Worksheet II-2) | | | | | |
| 9a | $\Delta IVTT_{VP}$ | Δ = _____ | R/S | | | |
| 9b | $\Delta OVTT_{VP}$ | Δ = _____ | R/S | | | |
| 9c | $\Delta OPTC_{VP}$ | Δ = _____ | R/S | | | |
| 9d | $\Delta INCENT_{VP}$ *** | Δ = _____ | R/S | | | |
| 9e | $\Delta 5_{VP}$ ** | Δ = _____ | R/S | | | |

* This must equal 0 or 1 unless the carpool subroutine is used, in which case it must be between 0 and 1 inclusive.

** If default coefficients are used, these Δ's must equal 0.

*** 9d must equal zero if STEP 7 was used.

## WORKSHEET C-4
(continued)
(3MODE(VAN)-AGG-2(B)/790110/ESE)

### USER INSTRUCTIONS

| STEP | PROCEDURE | ENTER | PRESS | | | DISPLAY |
|---|---|---|---|---|---|---|
| 10 | Market segment results | | B | | | |
| 10a | New DA share * | | | | | $S'_{DA}$ = ______ |
| 10b | New DA volume | | | | | $VOL'_{DA}$= ______ |
| 10c | New DA VMT | | R/S | | | $VMT'_{DA}$= ______ |
| 10d | New CP share * | | R/S | | | $S'_{CP}$ = ______ |
| 10e | New CP volume | | | | | $VOL'_{CP}$= ______ |
| 10f | New CP VMT | | R/S | | | $VMT'_{CP}$= ______ |
| 10g | New T share * | | R/S | | | $S'_{T}$ = ______ |
| 10h | New T volume | | | | | $VOL'_{T}$ = ______ |
| 10i | New VP share * | | R/S | | | $S'_{VP}$ = ______ |
| 10j | New VP volume | | | | | $VOL'_{VP}$= ______ |
| 10k | New VP VMT | | R/S | | | $VMT'_{VP}$= ______ |
| 10l | New Other share * | | R/S | | | $S'_{O}$ = ______ |
| 10m | New VMT for this market segment | | | | | $VMT'_{TOT}$= ______ |
| 10n | New Autos per worker *<br>These results can also be recorded on Worksheet II-6 | | R/S | | | A/W' = ______ |
| 11 | To analyze another market segment and have the results aggregated with previously analyzed market segments, press $\boxed{C}$ and GO TO STEP 4 | | C | | | |
| | To print** aggregated results of all previous market segments, press $\boxed{E}$ | | E | | | $\Sigma VOL'_{DA}$= ______<br>$\Sigma VMT'_{DA}$= ______<br>$\Sigma VOL'_{CP}$= ______<br>$\Sigma VMT'_{CP}$= ______<br>$\Sigma VOL'_{T}$ = ______<br>$\Sigma VOL'_{VP}$= ______<br>$\Sigma VMT'_{VP}$= ______<br>$\Sigma VMT_{TOT}$= ______<br>$\Sigma VMT'_{TOT}$= ______<br>$\Delta\Sigma VMT_{TOT}$= ______<br>$\%\Delta\Sigma VMT_{TOT}$= ______ |
| | These results can also be recorded on Worksheet II-6 | | | | | |
| | To analyze a new policy (no aggregation with previous market segments), press $\boxed{A}$ and GO TO STEP 2. (Since this sets memories to zero, data from previously tested policies must be copied before A is pressed, and user-supplied coefficients, if any, must be re-entered in STEP 3. | | A | | | |

---

* Printed but not displayed

**See Comments (Section 4) for retrieving data without a printer.

WORKSHEET C-5

Policy:__________________________

CARPOOL SUBROUTINE

Output from Step 5 - Input to Step 8
(all data items represent round trips)

| Population Subgroup | New Shared Ride Occupancy | Average Shared Ride IVTT | Average Shared Ride OVTT | Average Shared Ride OPTC | Average Shared Ride "Incentive" |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

WORKSHEET C-6

Policy:____________________

## RESULTS BY MARKET SEGMENT

| Population Subgroup | Base Autos Per Worker | Base VMT | New Drive Alone | | | New Carpool | | | New Transit | | New Vanpool | | | New Other Share | New VMT | New Autos Per Worker |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Share | Vol | VMT | Share | Vol | VMT | Share | Vol | Share | Vol | VMT | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| TOTALS | ☒ | | ☒ | | | ☒ | | | ☒ | | ☒ | | | ☒ | | ☒ |

| Change in VMT | Percent Change in VMT |
|---|---|
| | |

## H. COMMENTS

### 1. Use of Default Coefficients

If a printer is not used, the values which are printed/displayed must be copied from the calculator display. See note for Step 11 to get cumulative VMT values.

### Step 4 Copy data from Worksheet C-1

If income is not needed for this market segment (i.e., there is no change in cost for any mode), then a "1" should be entered for income. Market segment population should be entered as the total number of work trips. If a zero value is entered for any market segment data, the program output will be meaningless.

### Step 5 Copy data from Worksheet C-3

If the policy being analyzed affects carpools differently based on occupancy, the carpool subroutine should be used.* This subroutine gives a revised carpool occupancy and average changes in level of service for all carpools, regardless of occupancy.

The subroutine handles only two classes of carpools. In many cases, policies which discriminate by carpool occupancy do so on a two-person versus three-or-more person basis. If a policy affects four-or-more person carpools differently than two- and three-person carpools, the subroutine should be run with these two carpool classes.

---

* For example, a policy of free bridge tolls for three-or-more person carpools or preferential highway lanes for four-or-more person carpools.

The occupancy of two-person carpools is 2.0 and this should be eneterd as $OCC_1$ unless two- and three-person carpools are considered as a group. In the latter case, an occupancy value between two and three will be entered. The second occupancy is of three-or-more or four-or-more person carpools, as appropriate.

Changes in level of service represent round trips. They should be entered in the order shown, first for carpool class 1 and then for carpool class 2. The shares for the two classes of carpools (Steps 5b6 and 5b12) must sum to one.

Step 5c1 gives the new average occupancy of all carpools, which is automatically stored for use in the main program. Step 5c2 (repeated as many times as necessary) gives new average changes in level of service for all carpools. These values must be manually input in Steps 8f to 8i.

Step 6 Copy data from Worksheet C-1

The sum of the five mode shares must be one. Although "autos per worker" is not required as a variable in this model, provision is made for the input of a base value, so that changes in autos available for non-work travel, useful in some non-work models, can be computed by the program.

### Step 7

If the base vanpool share equals zero but the tested policy will result in a non-zero vanpool share, the vanpool subroutine must be used. A non-zero base share must be used on which to pivot the vanpool mode share. When the "base" vanpool share is entered in the subroutine (Step 7), the other base shares are automatically revised so that they still sum to one. The assumptions and logic of these changes are found above in Section D.2.

### Step 8 Copy data from Worksheet C-2 and Worksheet C-5

The changes in level of service are entered in minutes or cents, as appropriate, from the values on worksheet C-2 and/or worksheet C-5 (if the carpool subroutine is used). Note that when the default coefficients are used, Steps 8d, 8e, 8j, 8n, and 8o equal zero and must be entered as such.

If there are no changes in level of service[1] for the market segment, $\boxed{B}$ should be pressed just after $\boxed{D}$ and the user can continue with Step 10. If there is no change in level of service for transit and vanpool, the user may press $\boxed{B}$ after Step 8j is completed and then continue with Step 10. Similarly, if there is no change in level of service for carpool, transit, and vanpool, $\boxed{B}$ may be pressed after Step 8e.

---

[1] Market segments with no changes in level of service will often be used to ensure that the total base VMT can be determined, even though these market segments will have no changes in mode shares.

Incentives for carpool (Step 8i) is a variable which usually equals either zero or one. If the carpool subroutine is used, the carpool incentive may take on any value from zero to one inclusive.

Step 9 Copy data from Worksheet C-2

If the base vanpool share is zero and Step 7 was not used, the program automatically skips Step 9. Vanpool incentives (Step 9d) should equal zero if Step 7 was used to create a base vanpool share. Step 9e must equal zero when default coefficients are used.

Step 10

If a printer is not used, each value should be copied to Worksheet C-4 as it is displayed. The revised modal shares by market segment can also be displayed by pressing:

RCL 24 - $S'_{DA}$
RCL 25 - $S'_{CP}$
RCL 26 - $S'_{T}$
RCL 27 - $S'_{VP}$
RCL 28 - $S'_{O}$

Step 11

If a printer is not used, these values may be displayed by pressing

RCL 29

RCL 30

⋮

RCL 39

which correspond to $\Sigma VOL'_{DA}$, $\Sigma VMT'_{DA}$, . . . and $\%\Delta\Sigma VMT_{TOT}$ respectively. These values should be copied to Worksheet C-6.

## 2. User-Supplied Coefficients

If user-supplied coefficients are desired for the analysis of any policy, they can be easily entered in Step 3. All coefficients or as few as one may be changed; any coefficient not specifically changed in Step 3 will have the default value assigned to it in Step 2.[1] If the model specification is not changed, all instructions for Step 4 and so on, are valid. That is, if the first value (STO 00) is the coefficient of in-vehicle travel time (IVTT) for the drive-alone mode, the second value (STO 01) is the coefficient of out-of-vehicle travel time divided by distance (OVTT/DIST) for the drive-alone mode, etc; then the user need not be concerned with the explanations below and can follow all instructions for use of the default coefficients.

## 3. User-supplied Model Specification and Coefficients

The program was written for ease of execution using the default coefficients, while allowing for the possible substitution of alternative model specifications and coefficients. Basically, the program is capable of handling up to five coefficients for each of the three modes, with the coefficients of the fourth mode constrained to equal those of the second mode. Some of the coefficients stored in registers 00 through 14 are modified in the program by socioeconomic values. (See Table C.1

---

[1] User-supplied coefficients may be stored in any order in Step 3 as long as the appropriate STO XX is entered after the coefficient value.

above, variables 3, 4, and 5.) Any change in program specification must take this into account.

The easiest method of avoiding the effect of socioeconomic data in the utility equations is the storage of user-supplied coefficients in the first, fourth, and fifth places for each mode. (This corresponds to storage registers 0, 3, 4, 5, 8, 9, 10, 13, and 14, which are unaffected by income, or trip distance values in the utility equation.) The program user must take care to enter zero for the change in level of service for the second and third coefficient places, if this method is used.

An alternate method (which must be used when there are more than three relevant coefficients for any one mode) is to compensate for the division of a variable by a socioeconomic value by multiplying the input value by the same value. For instance, the default model takes ΔOVTT and automatically divides it by round-trip distance. If this modification is not desired, the true value of ΔOVTT should be multiplied by the round-trip distance so that the division done in the program will result in:

$$\frac{\Delta\text{OVTT} * \text{round-trip distance}}{\text{round-trip distance}} = \Delta\text{OVTT}$$

The user who wishes to change the default specification is advised to study section D.1 of this Appendix and to have a thorough understanding of the capacity and limits of the program as written.

## I. EXAMPLE

The following completed worksheets illustrate the analysis of preferential treatment for buses which decreased the average peak period transit travel time to downtown by ten minutes for in-vehicle time and two minutes for out-of-vehicle time. Three market segments represent all workers in the urban area:

1. Downtown workplace; all modes available
2. Downtown workplace, drive-alone not available
3. Workplace not downtown -- unaffected

The analysis results in Figure C.2 show that for market segments one and two, the transit mode shares increase, while all other non-zero mode shares decrease in proportion to their original share. The total VMT for these market segments decreases since transit ridership does not contribute to vehicle-miles travelled.

There are no changes in level of service for market segment three which consists of all unaffected workers. This market segment is included so that its VMT is part of the urban-wide base VMT used to calculate a final percent change in VMT attributable to the policy. For this analysis, the absolute change in VMT is -2200 and the percent change is -3.66.

## FIGURE C.2

### Printed Analysis Results

Market Segment 1*

```
       0.53
     37100.
 .4246662528
  2972.66377
  29726.6377
 .1887405568
 1321.183898
 5284.735591
 .2922229119
 2045.560384
          0.
          0.
          0.
 .0943702784
 35011.37329
 .5001624756
```

Market Segment 3*

```
    0.79
  22120.
    0.65
   1300.
  18200.
    0.35
    700.
   3920.
      0.
      0.
      0.
      0.
      0.
      0.
  22120.
    0.79
```

Market Segment 2*

```
        0.16
        960.
          0.
          0.
          0.
 .3534579374
 353.4579374
 848.2990498
 .5139953361
 513.9953361
          0.
          0.
          0.
 .1325467265
 848.2990498
 0.141383175
```

Aggregated Results**

```
  4272.66377      29
  47926.6377      30
 2374.641835      31
 10053.03464      32
  2559.55572      33
          0.      34
          0.      35
      60180.      36
 57979.67234      37
-2200.327661      38
-3.656244036      39
```

Printer Output

* These data values correspond to Worksheet C-4 Step 10
**These data values correspond to Worksheet C-4 Step 11

## II. DETAILED DOCUMENTATION: INCREMENTAL WORK TRIP MODE CHOICE MODEL (3MODE-VAN-AGG)

### A. DETAILED LOGIC

Step 1 - Read program from cards

Step 2 - Load register 0 - 14 -- default coefficients
Set registeres 15 - 39 equal to zero

Step 3 (optional) - Load registers 0 - 14 -- user-supplied coefficients

Step 4 - Load registers 15 - 20 -- market segment data

Step 5 (optional) - CARPOOL SUBROUTINE
Load registers 21 - 22 -- carpool class occupancies
Calculate average carpool occupancy and levels of service with shares and changes in level of service by carpool class:

| Registers | Contents | Calculations |
|---|---|---|
| - | $\Delta U_{CP1}$ | $\Delta IVTT_{CP1} * \theta IVTT_{CP1}$<br>$+ \Delta OVTT/DIST_{CP1} * \theta OVTT/DIST_{CP1}$<br>$+ \Delta OPTC/Y_{CP1} * \theta OPTC/Y_{CP1}$<br>$+ \Delta INCENT_{CP1} * \theta INCENT_{CP1}$ |
| - | $\Delta U_{CP2}$ | $\Delta IVTT_{CP2} * \theta IVTT_{CP2}$<br>$+ \Delta OVTT/DIST_{CP2} * \theta OVTT/DIST_{CP2}$<br>$+ \Delta OPTC/Y_{CP2} * \theta OPTC/Y_{CP2}$<br>$+ \Delta INCENT_{CP2} * \theta INCENT_{CP2}$ |

Step 5 (continued)

| Registers | Contents | Calculations |
|---|---|---|
| - | DENOM | $S_{CP1} * e^{\Delta U_{CP1}}$<br>$+ S_{CP2} * e^{\Delta U_{CP2}}$ |
| 38 | $S'_{CP1}$ | $S_{CP1} * e^{\Delta U_{CP1}}$ / DENOM |
| 39 | $S'_{CP2}$ | $S_{CP2} * e^{\Delta U_{CP2}}$ / DENOM |
| 17 | $OCC_{CP}$ | $1/[(S'_{CP1}/OCC_{CP1}) + (S'_{CP2}/OCC_{CP2})]$ |
| (display) | $\Delta LOS_{CP}$ | $S'_{CP1} * \Delta LOS_{CP1} + S'_{CP2} * \Delta LOS_{CP2}$ |

**Step 6** - Load registers 24 - 28 -- base mode shares Calculate base autos per worker and base VMT for the market segment.

| register | contents | calculations |
|---|---|---|
| display | A/W | $S_{CP}/OCC_{CP} + S_{DA}$ |
| 21 | $VMT_{TOT}$ | $A/W + \frac{S_{VP} * CIRC}{OCC_{VP}} * DIST * POP$ |

**Step 7** (optional) - Load register 27 -- adjusted vanpool share. Calculate adjusted DA, CP and T shares

| register | contents | calculations |
|---|---|---|
| 24 | $S^a_{DA}$ | $S_{DA} - .5 * S_{VP} (1 - S_T)$ |
| 25 | $S^a_{CP}$ | $S_{CP} - .5 * S_{VP} (1 - S_T)$ |
| 26 | $S^a_T$ | $S_T (1 - S_{VP})$ |

Step 8 - Calculate revised modal utilities due to changes in level of service.

| Register | Contents | Calculation |
|---|---|---|
| - | $\Delta U_{DA}$ | $\Delta IVTT_{DA} * \theta IVTT_{DA}$<br>$+ \Delta OVTT/DIST_{DA} * \theta OVTT/DIST_{DA}$<br>$+ \Delta OPTC/Y_{DA} * \theta OPTC/Y_{DA}$<br>$+ \Delta 4_{DA} * \theta 4_{DA} + \Delta 5_{DA} * \theta 5_{DA}$ |
| - | $\Delta U_{CP}$ | $\Delta IVTT_{CP} * \theta IVTT_{CP}$<br>$+ \Delta OVTT/DIST_{CP} * \theta OVTT/DIST_{CP}$<br>$+ \Delta OPTC/Y_{CP} * \theta OPTC/Y_{CP}$<br>$+ \Delta INCENT_{CP} * \theta INCENT_{CP}$<br>$+ \Delta 5_{CP} * \theta 5_{CP}$ |
| - | $\Delta U_{T}$ | $\Delta IVTT_{T} * \theta IVTT_{T}$<br>$+ \Delta OVTT/DIST_{T} * \theta OVTT/DIST_{T}$<br>$+ \Delta OPTC/Y_{T} * \theta OPTC/Y_{T}$<br>$+ \Delta 4_{T} * \theta 4_{T} + \Delta 5_{T} * \theta 5_{T}$ |

Step 9 (optional) - Calculate revised vanpool utility using changes in vanpool level of service.

| Register | Content | Calculation |
|---|---|---|
| - | $\Delta U_{VP}$ | $\Delta IVTT_{VP} * \theta IVTT_{VP}$<br>$+ \Delta OVTT/DIST_{VP} * \theta OVTT/DIST_{VP}$<br>$+ \Delta OPTC/Y_{VP} * \theta OPTC/Y_{VP}$<br>$+ \Delta INCENT_{VP} * \theta INCENT_{VP}$<br>$+ \Delta 5_{VP} * \theta 5_{VP}$ |

Step 10 - Calculate new modal shares using base modal shares and changes in utilities ($\Delta U_m$)

| Register | Content | Calculation |
|---|---|---|
| - | DENOM | $\sum_i (\text{base share}_i) * e^{\Delta U_i}$ |
| 24 | $S'_{DA}$ | $(S_{DA}[\text{or } S^a_{DA}] * e^{\Delta U_{DA}})/DENOM$ |
| 25 | $S'CP$ | $(S_{CP}[\text{or } S^a_{CP}] * e^{\Delta U_{CP}})/DENOM$ |
| 26 | $S'_T$ | $(S_T[\text{or } S^a_T] * e^{\Delta U_T})/DENOM$ |
| 27 | $S'_{VP}$ | $(S_{VP} * e^{\Delta U_{VP}})/DENOM$ |
| 28 | $S'_O$ | $S_O/DENOM$ |

Display or print market segment revised modal shares, volumes, VMT, total VMT, and revised autos per worker

Step 11 - Display or print aggregated results

## B. REGISTERS :

### Input

| | |
|---|---|
| 00 | $\theta IVTT_{DA}$ |
| 01 | $\theta OVTT/DIST_{DA}$ |
| 02 | $\theta OPTC/Y_{DA}$ |
| 03 | $\theta 4_{DA}$ |
| 04 | $\theta 5_{DA}$ |
| 05 | $\theta IVTT_{CP}$ |
| 06 | $\theta OVTT/DIST_{CP}$ |
| 07 | $\theta OPTC/Y_{CP}$ |
| 08 | $\theta 4_{CP}$ |
| 09 | $\theta 5_{CP}$ |
| 10 | $\theta IVTT_{T}$ |
| 11 | $\theta OVTT/DIST_{T}$ |
| 12 | $\theta OPTC/Y_{T}$ |
| 13 | $\theta 4_{T}$ |
| 14 | $\theta 5_{T}$ |
| 15 | DIST |
| 16 | Y |
| 17 | $OCC_{CP}$ |
| 18 | POP |
| 19 | $OCC_{VP}$ |
| 20 | CIRC |
| 21 | $OCC_{CP1}$ |
| 22 | $OCC_{CP2}$ |
| 24 | $S_{DA}$ |
| 25 | $S_{CP}$ |
| 26 | $S_{T}$ |
| 27 | $S_{VP}$ |
| 28 | $S_{O}$ |

### Internal

| | |
|---|---|
| 22 | $S_{TOT}$ - interim |
| 23 | $S_{CP}$ - interim |
| 24 | $S_{DA}$ - interim |
| 25 | $S_{CP}$ - interim |
| 26 | $S_{T}$ - interim |
| 27 | $S_{VP}$ - interim |
| 38 | $S_{CP1}$ - interim |
| 39 | $S_{CP2}$ - interim |

### Output

| | |
|---|---|
| 21 | $VMT_{TOT}$ |
| 24 | $S'_{DA}$ |
| 25 | $S'_{CP}$ |
| 26 | $S'_{T}$ |
| 27 | $S'_{VP}$ |
| 28 | $S'_{O}$ |

| | |
|---|---|
| 29 | $\Sigma VOL'_{DA}$ |
| 30 | $\Sigma VMT'_{DA}$ |
| 31 | $\Sigma VOL'_{CP}$ |
| 32 | $\Sigma VMT'_{CP}$ |
| 33 | $\Sigma VOL'_{T}$ |
| 34 | $\Sigma VOL'_{VP}$ |
| 35 | $\Sigma VMT'_{VP}$ |
| 36 | $\Sigma VMT_{TOT}$ |
| 37 | $\Sigma VMT'_{TOT}$ |
| 38 | $\Delta\Sigma VMT_{TOT}$ |
| 39 | $\%\Delta\Sigma VMT_{TOT}$ |

## C. SYMBOLS AND CODES

Modes:

- DA = Drive Alone
- SR = Shared Ride
  - CP = Carpool
    - CP1 = Carpool class 1
    - CP2 = Carpool class 2
  - VP = Vanpool
- T = Transit
- O = Other
- TOT = All modes

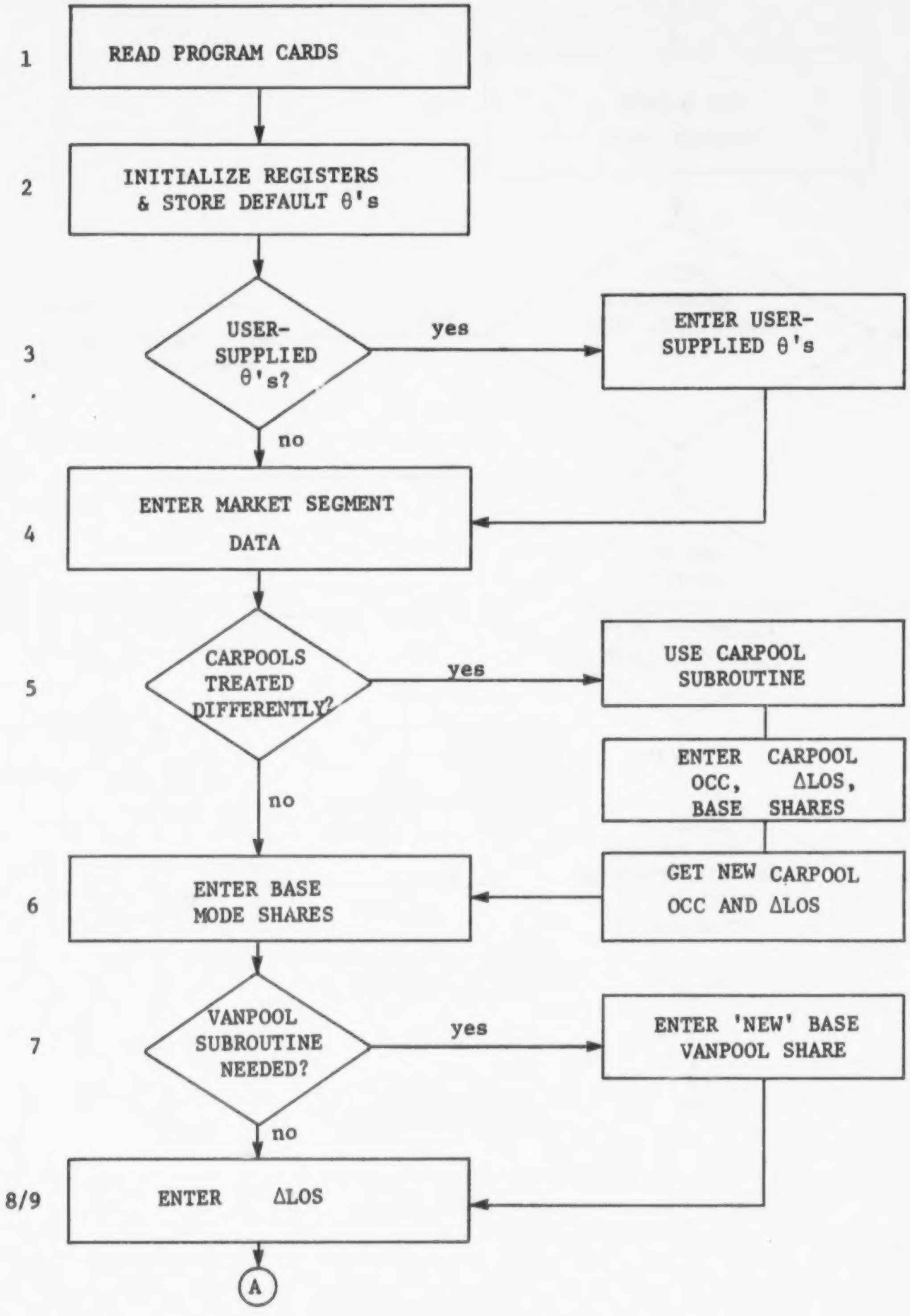
Variables:

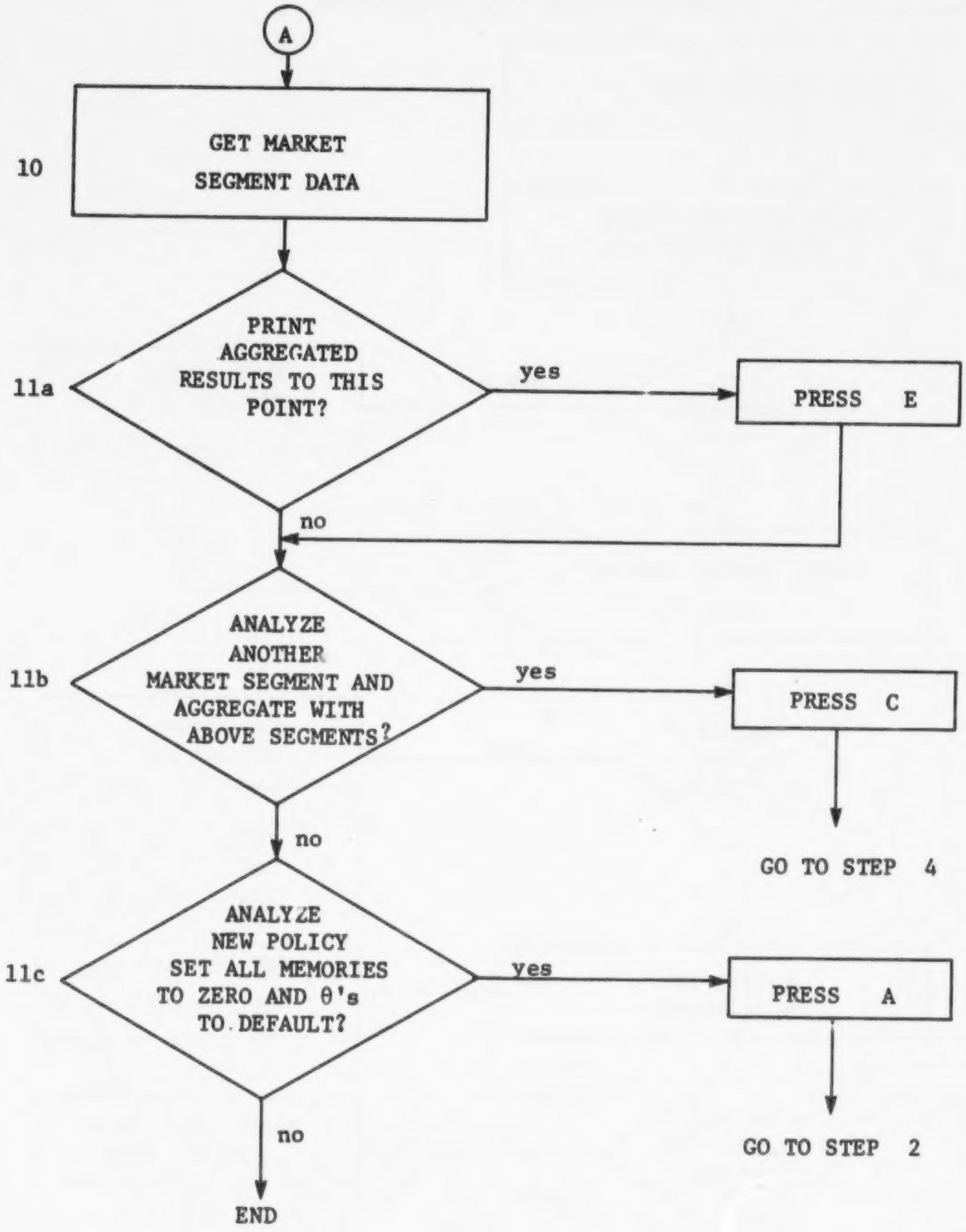
$IVTT_m$ = In-vehicle travel time for mode m
$OVTT_m$ = Out-of-vehicle travel time for mode m
$OPTC_m$ = Out-of-pocket travel cost for mode m
INCENT = Incentives for the carpool and vanpool modes only
DIST = Round-trip distance
Y = Average household income for a market segment
$OCC_m$ = Average vehicle occupancy for mode m
CIRC = Vanpool circuity factor
POP = Market segment population
$U_m$ = Utility of mode m
$VOL_m$, $VOL'_m$ = Base and new volume of mode m
$VMT_m$, $VMT'_m$ = Base and new vehicle-miles of travel for mode m
$S_m$, $S^a_m$, $S'_m$ = Base, adjusted, and new share of mode m
A/W, A/W' = Base and new autos per worker
$\Sigma x$ = Variable x, summed over all market segments

Other:

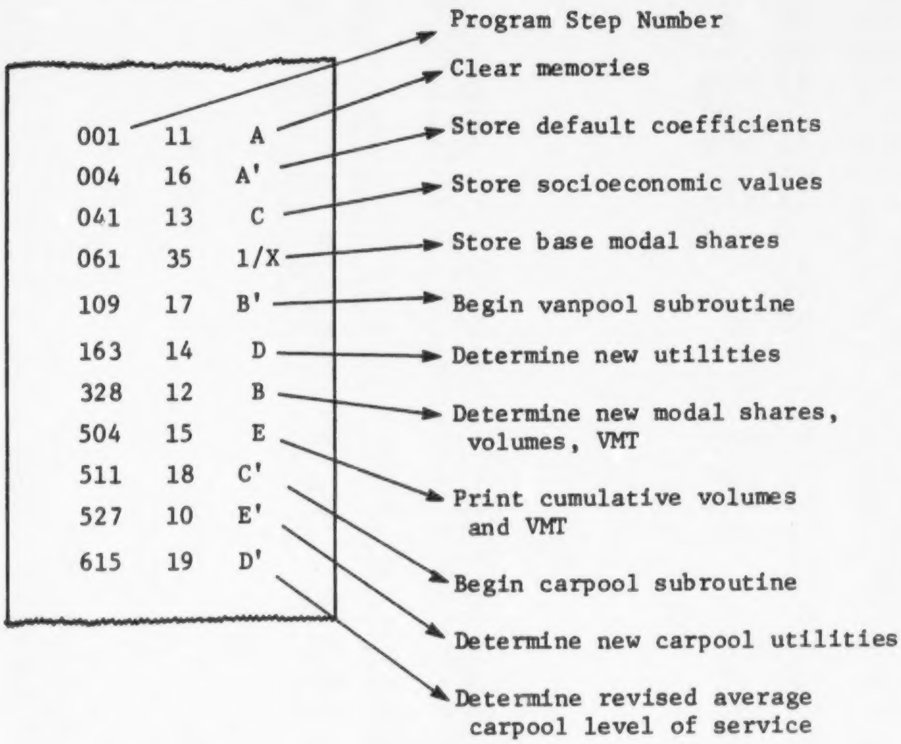
$\theta n_m$ = Coefficient of variable n for mode m
$\Delta n_m$ = Change in variable n for mode m

## D. FLOW CHART: (3MODE(VAN)-AGG-2(B)/790110/ESE)


1
READ PROGRAM CARDS
2
INITIALIZE REGISTERS & STORE DEFAULT θ's
3
USER-SUPPLIED θ's?
yes
ENTER USER-SUPPLIED θ's
no
4
ENTER MARKET SEGMENT DATA
5
CARPOOLS TREATED DIFFERENTLY?
yes
USE CARPOOL SUBROUTINE
ENTER CARPOOL OCC, ΔLOS, BASE SHARES
GET NEW CARPOOL OCC AND ΔLOS
no
6
ENTER BASE MODE SHARES
7
VANPOOL SUBROUTINE NEEDED?
yes
ENTER 'NEW' BASE VANPOOL SHARE
no
8/9
ENTER ΔLOS
A


A
10
GET MARKET SEGMENT DATA
11a
PRINT AGGREGATED RESULTS TO THIS POINT?
yes
PRESS E
no
11b
ANALYZE ANOTHER MARKET SEGMENT AND AGGREGATE WITH ABOVE SEGMENTS?
yes
PRESS C
GO TO STEP 4
no
11c
ANALYZE NEW POLICY SET ALL MEMORIES TO ZERO AND θ's TO DEFAULT?
yes
PRESS A
GO TO STEP 2
no
END

## E. LABELS:


Program Step Number
001 11 A
004 16 A'
041 13 C
061 35 1/X
109 17 B'
163 14 D
328 12 B
504 15 E
511 18 C'
527 10 E'
615 19 D'
Clear memories
Store default coefficients
Store socioeconomic values
Store base modal shares
Begin vanpool subroutine
Determine new utilities
Determine new modal shares, volumes, VMT
Print cumulative volumes and VMT
Begin carpool subroutine
Determine new carpool utilities
Determine revised average carpool level of service

## F. FLAGS:

None used

## G. CARD FORMATS:

None used

## H. PROGRAM LISTING

```
000  76 LBL
001  11  A
002  47 CMS
003  76 LBL
004  16  A'
005  93  .
006  00  0
007  01  1
008  05  5
009  94 +/-
010  42 STO
011  00  00
012  42 STO
013  05  05
014  42 STO
015  10  10
016  93  .
017  03  3
018  02  2
019  94 +/-
020  42 STO
021  01  01
022  42 STO
023  06  06
024  42 STO
025  11  11
026  02  2
027  09  9
028  94 +/-
029  42 STO
030  02  02
031  42 STO
032  07  07
033  42 STO
034  12  12
035  93  .
036  02  2
037  09  9
038  42 STO
039  08  08
040  76 LBL
041  13  C
042  91 R/S
043  42 STO
044  15  15
045  91 R/S
046  42 STO
047  16  16
048  91 R/S
049  42 STO
050  17  17
051  91 R/S
052  42 STO
053  18  18
054  91 R/S
055  42 STO
056  19  19
057  91 R/S
058  42 STO
059  20  20
060  76 LBL
061  35 1/X
062  91 R/S
063  42 STO
064  24  24
065  91 R/S
066  42 STO
067  25  25
068  91 R/S
069  42 STO
070  26  26
071  91 R/S
072  42 STO
073  27  27
074  91 R/S
075  42 STO
076  28  28
077  43 RCL
078  25  25
079  55  ÷
080  43 RCL
081  17  17
082  85  +
083  43 RCL
084  24  24
085  95  =
086  99 PRT
087  91 R/S
088  85  +
089  43 RCL
090  27  27
091  55  ÷
092  43 RCL
093  19  19
094  65  ×
095  43 RCL
096  20  20
097  95  =
098  65  ×
099  43 RCL
100  18  18
101  65  ×
102  43 RCL
103  15  15
104  95  =
105  44 SUM
106  36  36
107  99 PRT
108  76 LBL
109  17  B'
110  91 R/S
111  42 STO
112  27  27
113  43 RCL
114  26  26
115  75  -
116  53  (
117  43 RCL
118  26  26
119  65  ×
120  43 RCL
121  27  27
122  54  )
123  42 STO
124  22  22
125  95  =
126  42 STO
127  26  26
128  43 RCL
129  24  24
130  75  -
131  53  (
132  53  (
133  43 RCL
134  27  27
135  75  -
136  43 RCL
137  22  22
138  54  )
139  55  ÷
140  02  2
141  54  )
142  95  =
143  42 STO
144  24  24
145  43 RCL
146  25  25
147  75  -
148  53  (
149  53  (
150  43 RCL
151  27  27
152  75  -
153  43 RCL
154  22  22
155  54  )
156  55  ÷
157  02  2
158  54  )
```

```
159   95  =
160   42  STO
161   25   25
162   76  LBL
163   14   D
164   91  R/S
165   65   ×
166   43  RCL
167   00   00
168   85   +
169   91  R/S
170   65   ×
171   43  RCL
172   01   01
173   55   ÷
174   43  RCL
175   15   15
176   85   +
177   91  R/S
178   65   ×
179   43  RCL
180   02   02
181   55   ÷
182   43  RCL
183   16   16
184   85   +
185   91  R/S
186   65   ×
187   43  RCL
188   03   03
189   85   +
190   91  R/S
191   65   ×
192   43  RCL
193   04   04
194   95   =
195   22  INV
196   23  LNX
197   65   ×
198   43  RCL
199   24   24
200   95   =
201   42  STO
202   24   24
203   91  R/S
204   65   ×
205   43  RCL
206   05   05
207   85   +
208   91  R/S
209   65   ×
210   43  RCL
211   06   06
212   55   ÷
213   43  RCL
214   15   15
215   85   +
216   91  R/S
217   65   ×
218   43  RCL
219   07   07
220   55   ÷
221   43  RCL
222   16   16
223   55   ÷
224   43  RCL
225   17   17
226   85   +
227   91  R/S
228   65   ×
229   43  RCL
230   08   08
231   85   +
232   91  R/S
233   65   ×
234   43  RCL
235   09   09
236   95   =
237   22  INV
238   23  LNX
239   65   ×
240   43  RCL
241   25   25
242   95   =
243   42  STO
244   25   25
245   91  R/S
246   65   ×
247   43  RCL
248   10   10
249   85   +
250   91  R/S
251   65   ×
252   43  RCL
253   11   11
254   55   ÷
255   43  RCL
256   15   15
257   85   +
258   91  R/S
259   65   ×
260   43  RCL
261   12   12
262   55   ÷
263   43  RCL
264   16   16
265   85   +
266   91  R/S
267   65   ×
268   43  RCL
269   13   13
270   85   +
271   91  R/S
272   65   ×
273   43  RCL
274   14   14
275   95   =
276   22  INV
277   23  LNX
278   65   ×
279   43  RCL
280   26   26
281   95   =
282   42  STO
283   26   26
284   00   0
285   32  X:T
286   43  RCL
287   27   27
288   67   EQ
289   12   B
290   91  R/S
291   65   ×
292   43  RCL
293   05   05
294   85   +
295   91  R/S
296   65   ×
297   43  RCL
298   06   06
299   55   ÷
300   43  RCL
301   15   15
302   85   +
303   91  R/S
304   65   ×
305   43  RCL
306   07   07
307   55   ÷
308   43  RCL
309   16   16
310   55   ÷
311   43  RCL
312   19   19
313   85   +
314   91  R/S
315   65   ×
316   43  RCL
317   08   08
```

```
318  85   +
319  91  R/S
320  65   ×
321  43  RCL
322  09   09
323  95   =
324  22  INV
325  23  LNX
326  65   ×
327  76  LBL
328  12   B
329  43  RCL
330  27   27
331  95   =
332  42  STD
333  27   27
334  85   +
335  43  RCL
336  25   25
337  85   +
338  43  RCL
339  24   24
340  85   +
341  43  RCL
342  26   26
343  85   +
344  43  RCL
345  28   28
346  95   =
347  42  STD
348  22   22
349  43  RCL
350  24   24
351  55   ÷
352  43  RCL
353  22   22
354  95   =
355  42  STD
356  24   24
357  99  PRT
358  65   ×
359  43  RCL
360  18   18
361  95   =
362  99  PRT
363  91  R/S
364  44  SUM
365  29   29
366  65   ×
367  43  RCL
368  15   15
369  95   =
370  99  PRT
371  91  R/S
372  44  SUM
373  30   30
374  42  STD
375  21   21
376  43  RCL
377  25   25
378  55   ÷
379  43  RCL
380  22   22
381  95   =
382  42  STD
383  25   25
384  99  PRT
385  65   ×
386  43  RCL
387  18   18
388  95   =
389  99  PRT
390  91  R/S
391  44  SUM
392  31   31
393  55   ÷
394  43  RCL
395  17   17
396  65   ×
397  43  RCL
398  15   15
399  95   =
400  99  PRT
401  91  R/S
402  44  SUM
403  32   32
404  44  SUM
405  21   21
406  43  RCL
407  26   26
408  55   ÷
409  43  RCL
410  22   22
411  95   =
412  42  STD
413  26   26
414  99  PRT
415  65   ×
416  43  RCL
417  18   18
418  95   =
419  99  PRT
420  91  R/S
421  44  SUM
422  33   33
423  43  RCL
424  27   27
425  55   ÷
426  43  RCL
427  22   22
428  95   =
429  42  STD
430  27   27
431  99  PRT
432  65   ×
433  43  RCL
434  18   18
435  95   =
436  99  PRT
437  91  R/S
438  44  SUM
439  34   34
440  55   ÷
441  43  RCL
442  19   19
443  65   ×
444  43  RCL
445  15   15
446  65   ×
447  43  RCL
448  20   20
449  95   =
450  99  PRT
451  91  R/S
452  44  SUM
453  35   35
454  44  SUM
455  21   21
456  43  RCL
457  21   21
458  44  SUM
459  37   37
460  43  RCL
461  28   28
462  55   ÷
463  43  RCL
464  22   22
465  95   =
466  42  STD
467  28   28
468  99  PRT
469  43  RCL
470  21   21
471  99  PRT
472  91  R/S
473  43  RCL
474  37   37
475  75   -
476  43  RCL
```

```
477  36  36
478  95  =
479  42  STO
480  38  38
481  55  ÷
482  43  RCL
483  36  36
484  65  ×
485  01  1
486  00  0
487  00  0
488  95  =
489  42  STO
490  39  39
491  43  RCL
492  25  25
493  55  ÷
494  43  RCL
495  17  17
496  85  +
497  43  RCL
498  24  24
499  95  =
500  99  PRT
501  98  ADV
502  91  R/S
503  76  LBL
504  15  E
505  02  2
506  09  9
507  22  INV
508  90  LST
509  91  R/S
510  76  LBL
511  18  C'
512  02  2
513  01  1
514  42  STO
515  25  25
516  03  3
517  08  8
518  42  STO
519  26  26
520  91  R/S
521  42  STO
522  21  21
523  91  R/S
524  42  STO
525  22  22
526  76  LBL
527  10  E'
528  91  R/S
529  65  ×
530  43  RCL
531  05  05
532  85  +
533  91  R/S
534  65  ×
535  43  RCL
536  06  06
537  55  ÷
538  43  RCL
539  15  15
540  85  +
541  91  R/S
542  65  ×
543  43  RCL
544  07  07
545  55  ÷
546  43  RCL
547  16  16
548  55  ÷
549  73  RC*
550  25  25
551  85  +
552  91  R/S
553  65  ×
554  43  RCL
555  08  08
556  85  +
557  91  R/S
558  65  ×
559  43  RCL
560  09  09
561  95  =
562  22  INV
563  23  LNX
564  65  ×
565  91  R/S
566  95  =
567  72  ST*
568  26  26
569  01  1
570  44  SUM
571  25  25
572  44  SUM
573  26  26
574  91  R/S
575  43  RCL
576  38  38
577  85  +
578  43  RCL
579  39  39
580  95  =
581  42  STO
582  23  23
583  55  ÷
584  43  RCL
585  38  38
586  95  =
587  35  1/X
588  42  STO
589  38  38
590  43  RCL
591  39  39
592  55  ÷
593  43  RCL
594  23  23
595  95  =
596  42  STO
597  39  39
598  43  RCL
599  38  38
600  55  ÷
601  43  RCL
602  21  21
603  85  +
604  43  RCL
605  39  39
606  55  ÷
607  43  RCL
608  22  22
609  95  =
610  35  1/X
611  99  PRT
612  42  STO
613  17  17
614  76  LBL
615  19  D'
616  43  RCL
617  38  38
618  65  ×
619  91  R/S
620  85  +
621  43  RCL
622  39  39
623  65  ×
624  91  R/S
625  95  =
626  99  PRT
627  91  R/S
628  61  GTO
629  35  1/X
```

## APPENDIX D

## An Automotive Emissions Estimation Procedure

This appendix is structured into four parts:

- Calculation Procedure: an overview of the procedure with references to each Table and Worksheet used;
- Tables: data on percent cold-starts and factors for cold-starts, hot-soaks, and VMT-related emissions, to be applied as indicated in the Worksheets;
- Worksheets: forms which guide the user through the step-by-step calculation of automotive emissions;
- Interpolation Procedures: instructions for two- and three-dimensional interpolation, to be used if desired in conjunction with emission factor tables.

## D.1 Calculation Procedure

The method requires, for both a base case and any number of policy alternatives, levels of VMT and the number of trips in the study area. These data items can be obtained through the use of manual, calculator, or computerized-demand estimation techniques. The worksheets have been designed specifically, however, to be used in conjunction with the pivot-point demand estimation Worksheets I through V.[1] Since the output from the demand estimation worksheets is in terms of VMT only, Worksheet VI-A of the emissions estimation technique is used to calculate the number of trips for each appropriate market segment, based upon VMT data and average trip distance values. The average trip distance values appear as input data in the demand estimation worksheets.

Two alternative methods of estimating the percentage of trips beginning with a cold start are presented in Worksheet VI-B. Part 1 can be used only if parking duration data of the type described below are obtainable; Part 2 should be used in the more likely event that adequate parking data are not readily available.

The parking duration procedure included in Part 1 of Worksheet VI-B is based on the assumptions that vehicles equipped with a catalytic converter will start cold after the engine has been turned off one hour, and that a non-catalyst vehicle will start cold after four hours of disuse. The worksheet refers to Table D.1, which provides estimates of catalyst-equipped

---

[1] These worksheets are included in Appendix A and described in Section 3.1.1.

autos for a number of forecast years. If information is available indicating the percentage of trips involving automobiles which have been parked longer than one hour and longer than four hours, this part can be used. Depending on the level of aggregation of the data, this estimation procedure can be used in repeated applications to predict emissions produced by different market segments or by work and non-work trips. If the only available parking duration data are for total travel, then this worksheet can be used just once per policy.

Part 2, which should be used if parking duration data are not available, incorporates an explicit disaggregation of work and non-work trips. The fractions of trips with cold starts to be used in the emissions calculation in this worksheet are given in Table D.2. The frequency of cold starts differs among work and non-work trips, since the duration of parking time preceding the start of a non-work trip is normally shorter than that for work trips.

Worksheet VI-C is used to calculate total auto starting and evaporative emissions for both work and non-work travel by pollutant (HC, CO, and NOx). For each pollutant and purpose, start-up emissions are determined by multiplying the total trips by the HC, CO, and NOx factors in Tables D.3, D.4, and D.5. The emission factors in Tables D.3 and D.4 vary by percent cold starts, temperature, and forecast year. To use these tables, it is therefore first necessary to find the percent cold starts, applying the procedure presented in Worksheet VI-B. Users will in most cases find it necessary to interpolate in three dimensions to find the correct factor in

Tables D.3 and D.4 for specific percentages of cold starts, average temperatures, and forecast years.[1] The NOx emission factors in Table D.5 do not vary by temperature, although they do vary by year. Interpolation will generally be necessary to account for the percent of cold starts and forecast year.

Because they are related to the number of trips, evaporative HC emissions are also calculated using Worksheet VI-C. The quantity of hot-soak emissions is found by multiplying the number of auto trips by the appropriate hot-soak emission factors in Table D.6. The worksheet also provides for the summation of emissions by pollutant and by trip purpose, and of total by pollutant.

The next stage of the emissions estimation technique is calculation of VMT-related emissions, using Worksheet VI-D. This simply requires the multiplication of vehicle miles by travel by population subgroup and purpose by the factors given in Table D.7. Interpolation by speed and forecast year will generally be required.

As a final step, the total change in emission levels is calculated by summing the trip-related and VMT-related emissions using Worksheet VI-E. Inputs are obtained from Worksheets VI-C and VI-D for both base and revised alternatives. The worksheet also allows percentage changes by population subgroup and pollutant, and for all subgroups, to be computed.

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[1] Exact methods of linear interpolation in two and three dimensions appear in Section D.4.

## D.2 Tables

All emission factors appearing in Tables D.1 through D.7 come from the same U.S. DOT/EPA source (31). These tables include no correction factors for differences in the following variables, the values of which are held constant in all applications of the method:[1]

- percentage of travel by air-conditioned vehicles
- vehicle load
- percentage of travel by trailer-towing vehicles
- humidity

The tables also make no allowance for the effects of government-mandated vehicle inspection and maintenance programs, which will reduce emission levels relative to values given in the tables.

---

[1] More detailed estimation procedures recommended by EPA do include correction factors (29) for these variables.

## TABLE D.1

## Percent of Auto Trips by Catalyst-Equipped Vehicles

| Forecast Year | Percent of Auto Trips by Catalyst-Equipped Vehicles |
|---|---|
| 1977 | 38% |
| 1978 | 47 |
| 1979 | 57 |
| 1980 | 66 |
| 1981 | 76 |
| 1982 | 85 |
| 1983 | 88 |
| 1984 | 90 |
| 1985 | 93 |
| 1986 | 95 |
| 1987 | 98 |

Source: (70)

## TABLE D.2

## Percentage of Trips with Cold Starts

| Year | Work Trips | Non-work Trips |
|---|---|---|
| 1979 | 86% | 49% |
| 1980 | 88 | 51 |
| 1981 | 89 | 54 |
| 1982 | 90 | 57 |
| 1983 | 91 | 58 |
| 1984 | 91 | 58 |
| 1985 | 92 | 59 |
| 1986 | 92 | 59 |
| 1987 | 92 | 59 |

Sources:

1) percent cold starts by trip purpose data (69)
2) percent catalytic and non-catalytic-equipped vehicles per year (70)
3) trip frequency by trip purpose data (15)

TABLE D.3

Start-up Hydrocarbon Emission Factors (Grams/Trip)

| YEAR | PERCENT OF TRIPS STARTING COLD | TEMPERATURE (DEG. F) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| 1977 | 0 | 3.9 | 3.9 | 3.9 | 3.9 | 4.0 | 4.1 | 4.1 |
| | 10 | 6.1 | 5.7 | 5.3 | 5.0 | 4.9 | 4.7 | 4.5 |
| | 20 | 8.2 | 7.4 | 6.7 | 6.1 | 5.7 | 5.3 | 4.9 |
| | 30 | 10.4 | 9.1 | 8.0 | 7.2 | 6.6 | 5.9 | 5.4 |
| | 40 | 12.5 | 10.8 | 9.4 | 8.2 | 7.4 | 6.6 | 5.8 |
| | 50 | 14.7 | 12.6 | 10.8 | 9.3 | 8.3 | 7.2 | 6.3 |
| | 60 | 16.8 | 14.3 | 12.2 | 10.4 | 9.1 | 7.8 | 6.7 |
| | 70 | 19.0 | 16.0 | 13.6 | 11.5 | 10.0 | 8.5 | 7.2 |
| | 80 | 21.1 | 17.8 | 14.9 | 12.5 | 10.8 | 9.1 | 7.6 |
| | 90 | 23.3 | 19.5 | 16.3 | 13.6 | 11.7 | 9.7 | 8.0 |
| | 100 | 25.4 | 21.2 | 17.7 | 14.7 | 12.5 | 10.4 | 8.5 |
| 1962 | 0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.1 | 3.1 | 3.1 |
| | 10 | 4.3 | 4.0 | 3.8 | 3.6 | 3.6 | 3.5 | 3.4 |
| | 20 | 5.6 | 5.0 | 4.6 | 4.3 | 4.1 | 3.9 | 3.7 |
| | 30 | 6.8 | 6.1 | 5.4 | 4.9 | 4.7 | 4.3 | 4.0 |
| | 40 | 8.1 | 7.1 | 6.3 | 5.6 | 5.2 | 4.7 | 4.4 |
| | 50 | 9.4 | 8.1 | 7.1 | 6.2 | 5.7 | 5.2 | 4.7 |
| | 60 | 10.7 | 9.2 | 7.9 | 6.9 | 6.2 | 5.6 | 5.0 |
| | 70 | 12.0 | 10.2 | 8.7 | 7.5 | 6.8 | 6.0 | 5.3 |
| | 80 | 13.3 | 11.2 | 9.6 | 8.2 | 7.3 | 6.4 | 5.6 |
| | 90 | 14.6 | 12.3 | 10.4 | 8.8 | 7.8 | 6.8 | 6.0 |
| | 100 | 15.8 | 13.3 | 11.2 | 9.5 | 8.4 | 7.2 | 6.3 |
| 1987 | 0 | 3.2 | 3.2 | 3.2 | 3.2 | 3.3 | 3.3 | 3.3 |
| | 10 | 4.0 | 3.9 | 3.7 | 3.6 | 3.6 | 3.6 | 3.5 |
| | 20 | 4.9 | 4.6 | 4.3 | 4.1 | 4.0 | 3.9 | 3.7 |
| | 30 | 5.8 | 5.2 | 4.8 | 4.5 | 4.3 | 4.2 | 4.0 |
| | 40 | 6.6 | 5.9 | 5.4 | 4.9 | 4.7 | 4.4 | 4.2 |
| | 50 | 7.5 | 6.6 | 5.9 | 5.4 | 5.1 | 4.7 | 4.4 |
| | 60 | 8.3 | 7.3 | 6.5 | 5.8 | 5.4 | 5.0 | 4.6 |
| | 70 | 9.2 | 8.0 | 7.0 | 6.2 | 5.8 | 5.3 | 4.9 |
| | 80 | 10.0 | 8.7 | 7.5 | 6.7 | 6.1 | 5.6 | 5.1 |
| | 90 | 10.9 | 9.3 | 8.1 | 7.1 | 6.5 | 5.8 | 5.3 |
| | 100 | 11.8 | 10.0 | 8.6 | 7.5 | 6.8 | 6.1 | 5.5 |

Source: (70)

TABLE D.4

Start-up Carbon Monoxide Emission Factors (Grams/Trip)

| YEAR | PERCENT OF TRIPS STARTING COLD | TEMPERATURE (DEG. F) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 30 | 40 | 50 | 60 | 70 |
| 1977 | 0 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 |
| | 10 | 91.6 | 76.8 | 64.9 | 55.2 | 47.4 | 41.0 | 35.7 |
| | 20 | 168. | 138. | 114. | 95.0 | 79.3 | 66.5 | 56.0 |
| | 30 | 244. | 199. | 164. | 135. | 111. | 92.0 | 76.2 |
| | 40 | 320. | 261. | 213. | 174. | 143. | 117. | 96.5 |
| | 50 | 396. | 322. | 262. | 214. | 175. | 143. | 117. |
| | 60 | 472. | 383. | 312. | 254. | 207. | 168. | 137. |
| | 70 | 548. | 445. | 361. | 294. | 239. | 194. | 157. |
| | 80 | 624. | 506. | 411. | 333. | 271. | 219. | 177. |
| | 90 | 700. | 567. | 460. | 373. | 303. | 245. | 198. |
| | 100 | 776. | 629. | 509. | 413. | 334. | 270. | 218. |
| 1982 | 0 | 9.8 | 9.8 | 9.8 | 9.8 | 9.8 | 9.8 | 9.8 |
| | 10 | 61.7 | 50.8 | 42.5 | 36.0 | 30.9 | 26.9 | 23.8 |
| | 20 | 114. | 91.9 | 75.1 | 62.1 | 51.9 | 44.0 | 37.7 |
| | 30 | 165. | 133. | 108. | 88.2 | 73.0 | 61.1 | 51.7 |
| | 40 | 217. | 174. | 140. | 114. | 94.1 | 78.1 | 65.6 |
| | 50 | 269. | 215. | 173. | 141. | 115. | 95.2 | 79.6 |
| | 60 | 321. | 256. | 206. | 167. | 136. | 112. | 93.5 |
| | 70 | 373. | 297. | 238. | 193. | 157. | 129. | 107. |
| | 80 | 425. | 338. | 271. | 219. | 178. | 146. | 121. |
| | 90 | 477. | 379. | 304. | 245. | 199. | 164. | 135. |
| | 100 | 528. | 420. | 336. | 271. | 220. | 181. | 149. |
| 1987 | 0 | 9.7 | 9.7 | 9.7 | 9.7 | 9.7 | 9.7 | 9.7 |
| | 10 | 35.5 | 31.2 | 27.8 | 25.0 | 22.8 | 21.1 | 19.7 |
| | 20 | 61.4 | 52.7 | 45.8 | 40.4 | 36.0 | 32.5 | 29.7 |
| | 30 | 87.2 | 74.3 | 63.9 | 55.7 | 49.2 | 43.9 | 39.7 |
| | 40 | 113. | 95.8 | 82.0 | 71.1 | 62.3 | 55.3 | 49.7 |
| | 50 | 139. | 117. | 100. | 86.4 | 75.5 | 66.7 | 59.7 |
| | 60 | 165. | 139. | 118. | 102. | 88.7 | 78.2 | 69.7 |
| | 70 | 191. | 160. | 136. | 117. | 102. | 89.6 | 79.7 |
| | 80 | 217. | 182. | 154. | 133. | 115. | 101. | 89.7 |
| | 90 | 242. | 203. | 172. | 148. | 128. | 112. | 99.7 |
| | 100 | 268. | 225. | 191. | 163. | 141. | 124. | 110. |

Source: (70)

## TABLE D.5

## Start-up NOx Emission Factors (Grams/Trip)

| % of Trips Starting Cold | Year | | |
|---|---|---|---|
| | 1977 | 1982 | 1987 |
| 0 | 4.6 | 2.1 | 1.2 |
| 10 | 4.6 | 2.3 | 1.4 |
| 20 | 4.6 | 2.5 | 1.6 |
| 30 | 4.5 | 2.6 | 1.8 |
| 40 | 4.5 | 2.8 | 2.0 |
| 50 | 4.4 | 2.9 | 2.1 |
| 60 | 4.4 | 3.1 | 2.3 |
| 70 | 4.4 | 3.2 | 2.5 |
| 80 | 4.3 | 3.4 | 2.7 |
| 90 | 4.3 | 3.5 | 2.9 |
| 100 | 4.3 | 3.7 | 3.1 |

Source: (70)

## TABLE D.6

## Hot Soak Emission Factors

| Forecast Year | Hot Soak Factor (HC grams/trip) |
|---|---|
| 1977 | 11.8 |
| 1978 | 10.6 |
| 1979 | 9.4 |
| 1980 | 8.3 |
| 1981 | 7.1 |
| 1982 | 6.0 |
| 1983 | 5.2 |
| 1984 | 4.4 |
| 1985 | 3.6 |
| 1986 | 2.8 |
| 1987 | 2.2 |

Source: (70)

## TABLE D.7

## Auto Travel Emission Factors (Grams/Mile)

| | NMHC | | | CO | | | NOX | | |
|---|---|---|---|---|---|---|---|---|---|
| SPD | 1977 | 1982 | 1987 | 1977 | 1982 | 1987 | 1977 | 1982 | 1987 |
| 5.0 | 13.0 | 6.7 | 3.0 | 196.5 | 105.5 | 43.5 | 2.5 | 1.6 | 1.2 |
| 7.5 | 8.9 | 4.6 | 2.1 | 129.9 | 70.3 | 29.4 | 2.5 | 1.6 | 1.2 |
| 10.0 | 6.8 | 3.5 | 1.6 | 95.6 | 52.8 | 22.5 | 2.5 | 1.6 | 1.2 |
| 12.5 | 5.5 | 2.8 | 1.3 | 76.1 | 43.0 | 18.7 | 2.5 | 1.6 | 1.2 |
| 15.0 | 4.7 | 2.4 | 1.1 | 63.9 | 37.0 | 16.4 | 2.6 | 1.7 | 1.3 |
| 17.5 | 4.2 | 2.1 | 1.0 | 55.6 | 32.8 | 14.7 | 2.7 | 1.8 | 1.4 |
| 20.0 | 3.8 | 1.9 | 0.9 | 49.4 | 29.6 | 13.4 | 2.8 | 1.9 | 1.5 |
| 22.5 | 3.5 | 1.7 | 0.8 | 44.5 | 26.8 | 12.2 | 2.9 | 2.0 | 1.5 |
| 25.0 | 3.2 | 1.6 | 0.8 | 40.3 | 24.3 | 11.1 | 3.0 | 2.1 | 1.6 |
| 27.5 | 2.9 | 1.4 | 0.7 | 36.6 | 21.9 | 10.1 | 3.1 | 2.2 | 1.7 |
| 30.0 | 2.7 | 1.3 | 0.6 | 33.4 | 19.9 | 9.1 | 3.2 | 2.3 | 1.8 |
| 32.5 | 2.5 | 1.2 | 0.6 | 30.6 | 18.1 | 8.2 | 3.2 | 2.3 | 1.8 |
| 35.0 | 2.4 | 1.1 | 0.5 | 28.3 | 16.6 | 7.6 | 3.3 | 2.4 | 1.9 |
| 37.5 | 2.2 | 1.0 | 0.5 | 26.3 | 15.4 | 7.0 | 3.4 | 2.4 | 1.9 |
| 40.0 | 2.1 | 1.0 | 0.4 | 24.8 | 14.6 | 6.7 | 3.4 | 2.5 | 1.9 |
| 42.5 | 2.0 | 0.9 | 0.4 | 23.7 | 14.0 | 6.4 | 3.5 | 2.5 | 2.0 |
| 45.0 | 2.0 | 0.9 | 0.4 | 22.9 | 13.8 | 6.4 | 3.5 | 2.6 | 2.0 |
| 47.5 | 1.9 | 0.9 | 0.4 | 22.4 | 13.6 | 6.4 | 3.6 | 2.6 | 2.0 |
| 50.0 | 1.9 | 0.9 | 0.4 | 21.9 | 13.5 | 6.3 | 3.6 | 2.7 | 2.1 |
| 52.5 | 1.9 | 0.8 | 0.4 | 21.4 | 13.2 | 6.2 | 3.8 | 2.7 | 2.1 |
| 55.0 | 1.8 | 0.8 | 0.4 | 20.4 | 12.4 | 5.8 | 3.9 | 2.9 | 2.2 |
| 57.5 | 1.7 | 0.7 | 0.3 | 18.8 | 10.9 | 4.9 | 4.1 | 3.0 | 2.4 |
| 60.0 | 1.5 | 0.6 | 0.3 | 16.4 | 8.7 | 3.7 | 4.4 | 3.2 | 2.6 |

NOTE: These emission rates include travel-related emissions only. Trip end and diurnal emissions are excluded.

Source: (70)

## D.3 Worksheets

Worksheets VI-A through VI-E, desribed in Section D.1, appear on the pages which follow.

## VI-A. INPUT TRAVEL DATA SUMMARY FOR EMISSIONS ESTIMATION

☐ Base Alternative

☐ Revised Alternative

Forecast Year: ______________________

Policy: ______________________

| Population Subgroup | Work VMT (I or IV)[1] | ÷ | Average Work Trip Distance (miles)(I) | = | Number of One-Way Work Trips | Non-Work VMT (I or IV) | ÷ | Average Non-Work Trip Distance (miles) (I) | = | Non-Work Trips |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| Σ = | TOTAL WORK VMT | | Σ = | | TOTAL WORK TRIPS | Σ = TOTAL NON-WORK VMT | | Σ = | | TOTAL NON-WORK TRIPS |

TOTAL TRIPS

---

[1] Source Worksheets are indicated in parentheses where applicable. VMT and trips on worksheets I and IV in Appendix A must be multiplied by the number of households per population subgroup.

## VI-B. COLD START FRACTIONS

☐ Base Alternative

☐ Revised Alternative

Policy: ____________________

Subgroup: ____________________

Forecast Year: ____________________

1. If Daily Parking Duration Data are Available:

| % of Auto Trips by Catalyst-Equipped Vehicles (Table D.1) | | % of Auto Trips with Parking Duration 1 hour | | % of Auto Trips by Non-Catalyst Equipped Vehicles | | % of Auto Trips with Parking Duration 4 hours | | % of Auto Trips with Cold Starts |
|---|---|---|---|---|---|---|---|---|
| ☐ | X | ☐ | + | ☐ | X | ☐ | = | ☐ |

2. If Daily Parking Duration Data are not Available

% of Work Trip Cold Starts (Table D.2)

☐

% Non-Work Trip Cold Starts (Table D.2)

☐

## VI-C. AUTO START-UP AND EVAPORATIVE EMISSIONS

☐ Base Alternative

☐ Revised Alternative

Policy: ____________________

Forecast Year: ____________________

Temperature: ____________________

| | Work Trips | | | | | | Non-Work Trips | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (1) Population Subgroup | (2) % Cold Starts[1] (VI-B) | (3) Trips (IV-A) | Pollutant[2] | From Table[3] | (4) Start-Up Factors | (5) Emissions = Col. 3 X Col. 4 (grams) | (6) % Cold Starts (VI-B) | (7) Trips (VI-A) | (8) Start-Up Factors | (9) Emissions = Col. 3 X Col. 4 (grams) |
| | | | HC(c) | D.3 | | | | | | |
| | | | CO(c) | D.4 | | | | | | |
| | | | NOx(c | D.5 | | | | | | |
| | | | HC(h) | D.6 | | | | | | |
| | | | HC(c) | D.3 | | | | | | |
| | | | CO(c) | D.4 | | | | | | |
| | | | NOx(c | D.5 | | | | | | |
| | | | HC(h) | D.6 | | | | | | |
| | | | HC(c) | D.3 | | | | | | |
| | | | CO(c) | D.4 | | | | | | |
| | | | NOx(c | D.5 | | | | | | |
| | | | HC(h) | D.6 | | | | | | |

TOTALS

| TOTALS $\sum_{\text{Subgroups}}$ | Work Trip Start-Up Emissions (grams) | + | $\sum_{\text{Subgroups}}$ | Non-Work Trip Start-Up Emissions (grams) | = | Total Start-Up Emissions (grams) |
|---|---|---|---|---|---|---|
| HC | | | HC | | | |
| CO | | | CO | | | |
| NOx | | | NOx | | | |

---

[1] Source Worksheets are indicated in parentheses where applicable

[2] (c) indicates cold start factor

(h) indicates hot soak factor

[3] both work and non-work start-up factors obtained from the indicated tables

## VI-D. AUTO TRAVEL EMISSIONS

☐ Base Alternative

☐ Revised Alternative

Policy: ____________________

Forecast Year: ____________________

| | Work Trips | | | | Non-Work Trips | | | |
|---|---|---|---|---|---|---|---|---|
| (1) Population Subgroup | (2) Average Speed | (3) VMT (VI-A)[1] | (4) Auto Travel Factors (Table D.7) | (5) Emissions = Col. 3 X Col. 4 (grams) | (6) Average Speed | (7) VMT (VI-A) | (8) Auto Travel Factors (Table D.7) | (9) Emissions = Col. 7 X Col. 8 (grams) |
| | | | HC | | | | HC | |
| | | | CO | | | | CO | |
| | | | NOx | | | | NOx | |
| | | | HC | | | | HC | |
| | | | CO | | | | CO | |
| | | | NOx | | | | NOx | |
| | | | HC | | | | HC | |
| | | | CO | | | | CO | |
| | | | NOx | | | | NOx | |
| | | | HC | | | | HC | |
| | | | CO | | | | CO | |
| | | | NOx | | | | NOx | |
| | | | HC | | | | HC | |
| | | | CO | | | | CO | |
| | | | NOx | | | | NOx | |
| | | | HC | | | | HC | |
| | | | CO | | | | CO | |
| | | | NOx | | | | NOx | |

| TOTALS | $\sum_{\text{Subgroups}}$ | | + | $\sum_{\text{Subgroups}}$ | | = | |
|---|---|---|---|---|---|---|---|
| | HC | | | HC | | | |
| | CO | | | CO | | | |
| | NOx | | | NOx | | | |
| | | Work Trip Travel Emissions (grams) | | | Non-Work Trip Travel Emissions (grams) | | Total VMT Travel Emissions (grams) |

---

[1] Source Worksheets are indicated in parentheses where applicable

VI-E. SUMMARY OF CHANGES IN EMISSIONS

Revised Alternative

Policy:____________________

Forecast Year:____________________

| (1) Population Subgroup | | Base Emissions | | | Revised Emissions | | | (8) Change in Total Emissions (Col. 4-Col. 7) | (9) Percent Change in Emissions (Col. 8/Col.4) x 100 |
|---|---|---|---|---|---|---|---|---|---|
| | | (2) Trip-Related (VI-C)[1] | (3) Travel (VI-D) | (4) Total (Col. 2 + Col. 3) | (5) Trip-Related (VI-C) | (6) Travel (VI-D) | (7) Total (Col. 5+Col. 6) | | |
| | HC | | | | | | | | |
| | CO | | | | | | | | |
| | NOx | | | | | | | | |
| | HC | | | | | | | | |
| | CO | | | | | | | | |
| | NOx | | | | | | | | |
| | HC | | | | | | | | |
| | CO | | | | | | | | |
| | NOx | | | | | | | | |
| | HC | | | | | | | | |
| | CO | | | | | | | | |
| | $NO_x$ | | | | | | | | |

TOTALS

| $\sum$ Sub-groups | | Total Base Emissions (grams) |
|---|---|---|
| | HC | |
| | CO | |
| | NOx | |

| $\sum$ Sub-groups | | Total Change in Emissions (grams) | Percent Change, Total Emissions |
|---|---|---|---|
| | HC | | |
| | CO | | |
| | NOx | | |

---

[1] Source Worksheets are indicated in parentheses where applicable

## D.4 Interpolation Methods for Multi-Dimensional Tables

### D.4.1 Two-Dimensional Interpolation

This procedure can be used to obtain interpolated values of emissions factors from Table D.5 and D.7. In each table, let y equal the year, z equal the vertical dimension (percent of trips starting cold in Table D.5, and speed in Table D.7), and e equal the emission factors. Thus, $y_f$ and $z_f$ represent the specified input levels; $e_f$, the desired output factor.

a. Determine the bracketing values for both y and z; the largest values less than $y_f$ and $z_f$ ($y_1$ and $z_1$) and the smallest values greater than $y_f$ and $z_f$ ($y_2$ and $z_2$).

b. Determine the emission factors for each combination of bracketing values. Arrange these in a table of the following form:

| combination | emissions factors |
|---|---|
| $y_1, z_1$ | $e_{11}$ |
| $y_1, z_2$ | $e_{12}$ |
| $y_2, z_1$ | $e_{21}$ |
| $y_2, z_2$ | $e_{22}$ |

c. Calculate the following ratios:

$$f_y = \frac{y_f - y_1}{y_2 - y_1} \qquad f_z = \frac{z_f - z_1}{z_2 - z_1}$$

d. Compute the interpolated value:

$$\begin{aligned} e_f &= (1 - f_y)(1 - f_z) \cdot e_{11} \\ &+ (1 - f_y) \cdot f_z \cdot e_{12} \\ &+ f_y(1 - f_z) \cdot e_{21} \\ &+ f_y \cdot f_z \cdot e_{22} \end{aligned}$$

The following example shows the use of the procedure to obtain an interpolated value from Table D.5 corresponding to $y_f = 1979$, $z_f = 32$.

a. Determine bracketing values:

$$x_1 = 1977, \; x_2 = 1982$$

$$z_1 = 30, \quad z_2 = 40$$

b. Determine emissions factors:

| combination | emissions factor |
|---|---|
| 1977, 30 | $e_{11} = 4.5$ |
| 1977, 40 | $e_{12} = 4.5$ |
| 1982, 30 | $e_{21} = 2.6$ |
| 1982, 40 | $e_{22} = 2.8$ |

c. Calculate ratios:

$$f_y = \frac{1979 - 1977}{1982 - 1977} = 0.4$$

$$f_z = \frac{32 - 30}{40 - 30} = 0.2$$

d. Compute the interpolated value:

$$\begin{aligned} e_f &= 0.6 \bullet 0.8 \bullet 4.5 + \\ &\quad 0.6 \bullet 0.2 \bullet 4.5 + \\ &\quad 0.4 \bullet 0.8 \bullet 2.6 + \\ &\quad 0.4 \bullet 0.2 \bullet 2.8 = \quad 3.76 \end{aligned}$$

## D.4.2 Three-Dimensional Interpolation

The two-dimensional procedure can be extended to three dimensions for use with Tables D.3 and D.4. In each table, let t = temperature, p = percent of trips starting cold, y = year, and e = emission factor. As before, the subscript f deontes the desired values, and the subscripts 1 and 2 the bracketing values. The same steps are included in this procedure as those in the two-dimensional procedure. In each case, however, changes exist to reflect the number of dimensions.

An example from Table D.3 is shown integrated in each step. In this example, $t_f = 52$, $p_f = 36$, and $y_f = 1979$.

a. Determine the bracketing values $t_1$, $t_2$, $p_1$, $p_2$, $y_1$, $y_2$.

Example:

$t_1, t_2 = 50, 60$

$p_1, p_2 = 30, 40$

$y_1, y_2 = 1977, 1982$

b. Determine emission factors for each combination of bracketing values:

| combination | emission factor | Example<br>combination | emission factor |
|---|---|---|---|
| $t_1\ p_1\ y_1$ | $e_{111}$ | 50, 30, 1977 | 9.1 |
| $t_1\ p_1\ y_2$ | $e_{112}$ | 50, 30, 1982 | 6.1 |
| $t_1\ p_2\ y_1$ | $e_{121}$ | 50, 40, 1977 | 10.8 |
| $t_1\ p_2\ y_2$ | $e_{122}$ | 50, 40, 1982 | 7.1 |
| $t_2\ p_1\ y_1$ | $e_{211}$ | 60, 30, 1977 | 8.0 |
| $t_2\ p_1\ y_2$ | $e_{212}$ | 60, 30, 1982 | 5.4 |
| $t_2\ p_2\ y_1$ | $e_{221}$ | 60, 40, 1977 | 9.4 |
| $t_2\ p_2\ y_2$ | $e_{222}$ | 60, 40, 1982 | 6.3 |

c. Calculate ratios:

$$f_t = \frac{t_f - t_1}{t_2 - t_1}$$

$$f_p = \frac{p_f - p_1}{p_2 - p_1}$$

$$f_y = \frac{y_f - y_1}{y_2 - y_1}$$

Example

$$f_t = \frac{50 - 50}{60 - 50} = 0.2$$

$$f_p = \frac{36 - 30}{40 - 30} = 0.6$$

$$f_y = \frac{1979 - 1977}{1982 - 1977} = 0.4$$

d. Compute the interpolated value:

$$\begin{aligned}
e_f = {} & (1 - f_t)(1 - f_p)1 - f_y) \bullet e_{111} + \\
& (1 - f_t)(1 - f_p) \bullet f_y \bullet e_{112} + \\
& (1 - f_t) \bullet f_p(1 - f_y) \bullet e_{121} + \\
& (1 - f_t) \bullet f_p \bullet f_y \bullet e_{122} + \\
& f_t(1 - f_p)(1 - f_y) \bullet e_{211} + \\
& f_t(1 - f_p) \bullet f_y \bullet e_{212} + \\
& f_t \bullet f_p(1 - f_y) \bullet e_{221} + \\
& f_t \bullet f_p \bullet f_y \bullet e_{222}
\end{aligned}$$

Example:

$$\begin{aligned}
e_f = {} & 0.8 \bullet 0.4 \bullet 0.6 \bullet 9.1 + \\
& 0.8 \bullet 0.4 \bullet 0.4 \bullet 6.1 + \\
& 0.8 \bullet 0.4 \bullet 0.6 \bullet 10.8 + \\
& 0.8 \bullet 0.6 \bullet 0.4 \bullet 7.1 + \\
& 0.2 \bullet 0.4 \bullet 0.6 \bullet 0.8 + \\
& 0.2 \bullet 0.4 \bullet 0.4 \bullet 5.4 + \\
& 0.2 \bullet 0.6 \bullet 0.6 \bullet 9.4 + \\
& 0.2 \bullet 0.6 \bullet 0.4 \bullet 6.3 = \quad 8.54
\end{aligned}$$

# APPENDIX E

## An Automobile Fuel Consumption and Operating Cost Estimation Procedure

The inputs required to apply the manual method of estimating automotive fuel consumption and operating costs are listed in Table E.1, along with default values based on 1976 conditions. Various sources from which these input values may be obtained for particular localities and analysis years are also indicated. The method is based on urban-area travel data in the 10 to 40 mile per hour speed range and does not represent the decreased fuel economy which occurs at speeds greater than 40 miles per hour.

After determination of the input values for each population subgroup/trip purpose segment, the following steps are carried out:

1. Compute Fuel Consumption for Warmed-up Operation

$A = 0.009133 + 0.008426 \cdot WT$

$B = -0.004404 + 0.003637 \cdot WT$

$FWARM = (A \cdot DIST + B \cdot TIME) \cdot RFC$

2. Compute Temperature/Distance Correction Factor

$TDFAC = 1.0 + (TEMP - 10) \cdot 0.00503 \cdot DIST^{-0.3738}$

## TABLE E.1

## Inputs to the Automobile Fuel Consumption and Operating Cost Procedure

| Variable Name | Description | Defaults (1976 Conditions) | Source |
|---|---|---|---|
| **I. General, Related to Fuel Consumption** | | | |
| WT | Average passenger vehicle weight (1000 lbs) | 3.96 | local vehicle fleet data (6,3) |
| RFC | Impacts of all technological factors but vehicle weight on fuel consumption, relative to 1975 technology (ratio of analysis year fuel consumption to 1975 fuel consumption when vehicle weight reamins constant) | 1.00 | EPA data on fuel economy vs. vehicle weights |
| TEMP | Average ambient temperature (degrees celsius) | 10 | local weather data |
| **II. General, Related to Operating Costs** | | | |
| GCOST | Gasoline cost (dollars/gallon in analysis year dollars) | 0.60 | local gasoline sales data |
| RMTCOST | Repair, maintenance, and tire costs (dollars/mile in analysis year dollars) | 0.03 x 97 | Bureau of Labor Statistics (68) |
| **III. Population Subgroup and Trip Purpose Segment-Specific** | | | |
| TIME | Average one-way trip time (minutes) | - | Worksheet VI |
| DIST | Average one-way trip distance (miles) | - | Worksheet I |
| TPHH | Daily trips per household made by the group (daily one-way trips/household) | - | Worksheet I or VI-A |
| HHS | Total households in the group (households) | - | local data, Worksheet I |

3. Compute Cold Start Correction Factor

   a. If DIST is less than or equal to 3 miles,

   $$RCW = 0.5689 + 0.1447 \cdot \ln(DIST)$$

   b. If DIST is greater than 3 miles, and less than or equal to 25 miles,

   $$RCW = 0.6187 + 0.1022 \cdot \ln(DIST)$$

   c. If DIST is greater than 25 miles,

   $$RCW = 0.95$$

4. Compute Fuel Consumption for the Segment (FUEL is in gallons per day)

   $$FUEL = FWARM \cdot TPHH \cdot HHS/(RCW \cdot TDFAC)$$

5. Compute Operating Costs for the Segment (OCOST is in analysis year dollars per day)

   $$OCOST = FUEL \cdot GCOST + DIST \cdot RMTCST \cdot TPHH \cdot HHS$$

Values obtained for separate population subgroups and trip purpose segments can be summed to obtain estimates of analysis area totals.

As an example of the procedure's application, consider the case in which all general input variables take on their default values, and the following values have been estimated for all work trips in an urban area following implementation of a policy alternative oriented to improving air quality:

TIME = 25 minutes
DIST = 14 miles
TPHH = 2.1 daily work trips/household
HHS = 15,700 households

The steps described above follow:

1. $A = 0.009133 + 0.008426 \cdot 3.96$

   $= 0.0425$

   $B = -0.004404 + 0.003637 \cdot 3.96$

   $= 0.01$

   $FWARM = (0.0425 \cdot 14 + 0.01 \cdot 25) \cdot 1.0$

   $= 0.845$

2. $TDFAC = 1.0 + (10 - 10) \cdot 0.00503 \cdot 14^{-0.3738}$

   $= 1.0$

3. DIST = 14, so 3b. is used:

   $RCW = 0.6187 + 0.1022 \ln (14)$

   $= 0.8884$

4. $FUEL = 0.845 \cdot 2.1 \cdot 15{,}700/(0.8884 \cdot 1.0)$

   = 31,360 gallons/day

5. $OCOST = 31{,}360 \cdot 0.60 + 14 \cdot 0.0397 \cdot 2.1 \cdot 15{,}700$

   = 37,140 dollars/day (1976 $)

## APPENDIX F

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